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USAAVLABS TECHNICAL REPORT 69-47

A STUDY OF TASK PERFORMANCE AND HANDLING QUALITIES EVALUATION TECHNIQUES AT HOVER AND IN LOW-SPEED FLIGHT

By

H. P. Harper
W. Sardanowsky

July 1969

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-67-C-0098
UNITED AIRCRAFT CORPORATION
SIKORSKY AIRCRAFT DIVISION
STRATFORD, CONNECTICUT

U. S. ARMY MATERIEL COMMAND

228

DEPARTMENT OF THE ARMY
HEADQUARTERS US ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS VIRGINIA 23604

This report was prepared by the Sikorsky Aircraft Division, United Aircraft Corporation, under the terms of Contract DAAJ02-67-C-0098. This work consists of a hover and low-speed handling qualities evaluation conducted with the S-61F compound helicopter for the purpose of studying task performance evaluation techniques. Effects of changes in configuration on task performance precision, pilot work load, and pilot opinion were evaluated.

This program is part of a progressive series of handling qualities research programs designed to provide increased understanding of the man-vehicle interface and to improve the task performance and handling qualities evaluation techniques of future concepts. The objectives of the program were generally met. It was shown that no single type of data can adequately represent an aircraft's handling characteristics. Pilot opinion, control activity, and mission task performance precision each reveal only one aspect of the overall handling qualities evaluation problem. A combination of parameters is necessary to adequately represent the mission task performance capability of a concept.

The conclusions and recommendations contained in this report are concurred in by this Command. This concurrence will hopefully manifest itself in additional research programs for the purpose of quantifying factors such as pilot work load and pilot performance. Results of these efforts will benefit the designer of any future concept as well as the procuring activity.

Task 1F162204A14233
Contract DAAJ02-67-C-0098
USAAVLABS Technical Report 69-47
July 1969

A STUDY OF TASK PERFORMANCE AND HANDLING QUALITIES EVALUATION TECHNIQUES AT HOVER AND IN LOW-SPEED FLIGHT

SER-611455

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SUMMARY

A flight test study was conducted to evaluate the effects of compound configuration on helicopter flying and handling qualities in low-speed flight and to develop task performance evaluation techniques. The S-61F compound helicopter test-bed aircraft was used to perform a series of hover and low-speed tasks while objective measures and pilot opinion data were recorded. To allow evaluation of the statistical significance of the data, three pilots performed each task five times. Objective data were recorded using specially equipped Automax cameras placed on the field, and on-board photo panel and FM tape-recording equipment. Pilot opinions of work load, task performance precision and aircraft handling qualities were recorded after each trial for comparison with the objective data. The task sequences were first performed in the full compound configuration and then repeated with the wings and horizontal stabilizer removed. This provided data for an evaluation of the influence of the wing and horizontal stabilizer on helicopter flying and handling qualities. Data analysis was performed on the UNIVAC 1108.

The effect of wing and horizontal stabilizer was to increase longitudinal stability and to reduce lateral response in forward flight. Around hover, rotor downwash impingement on the horizontal tail produced random pitching motion, accompanied by an improvement in longitudinal hover precision. One of the most important findings of this study was the requirement for pilot work load, pilot opinion and actual task performance percision information for a realistic evaluation of task performance capability. None of these measures alone covers the information provided by the two other parameters. Pilot opinion measures were found to lack sufficient uniformity for use as an absolute flying qualities evaluation parameter. In some cases the three pilots expressed different opinions regarding the effect on flying qualities of the same change in aircraft configuration. Measures of control rate and amplitude were found to be a sensitive indicator of configuration changes. The data analyses showed the importance of selecting the proper measures when task performance precision requirements are stated. The results of this study form the basis for further development of mission task performance oriented design criteria. The data and techniques generated in this study should be applied to an in-field evaluation of critical mission task performance tolerances and further work to establish the relationship between design parameters and aircraft task performance capability.

FOREWORD

This report covers the work performed by the Sikorsky Division of the United Aircraft Corporation under Contract DAAJ02-67-C-0098, Task 1F162204A14233, for the U.S. Army Aviation Materiel Laboratories. The program was monitored by Mr. Richard L. Scharpf of the Applied Aeronautics Division.

The authors acknowledge with gratitude the efforts of the personnel of Sikorsky's Advanced Research Branch, Flight Test Engineering Branch and Engineering Flight Office. Among those making substantial contributions were:

R. Didner	Advanced Research Branch
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LIST OF SYMBOLS

A_{ij}	Spectral Density Amplitude
f	Frequency of the Fourier Component x(f)
f_{ij}	Cross Spectral Density Function at Period
$K(v/m) = K(\tau)$	Spectral Window
m	Maximum Number of Lags
N	Number of Points in Each Time Series
P(f)	Power Spectrum of x(t)
PSD	Power Spectral Density
Q	The maximum Number of Periods to be Covered in the Spectral Density Functions
q_{ij}	Quadrature Spectrum
$R_{ij}(v)$	Cross Covariance Function Between Two Time Series x_i and x_j
$R(\tau)$	Auto-Correlation Function
$r_{ij}(v)$	Cross Correlation Function Between Two Time Series x_i and x_j
S	Two-Dimensional Array of Sums of Squares
T	Total Signal Length Under Consideration
t	Elapsed Time
v	Computational Lag Value
X	Measured Deviation
$\bar{X}$	Mean of Measured Deviation
x	Two-Dimensional Array of Time Series

$x(f)$	Fourier Component
$x(t)$	Signal Variation with Time t
τ	Time lag

INTRODUCTION

Research studies conducted at Sikorsky Aircraft over the past years have revealed significant lack of mission requirement consideration in the formulation of flying and handling qualities specifications. This is particularly true of proposed VTOL specifications, where "acceptable handling qualities" are demanded without regard to aircraft design missions. To overcome these deficiencies, the mission task performance oriented approach to flying and handling qualities specifications was developed. In this approach the flying and handling qualities specifications are based on mission task performance requirements for effective design mission accomplishment.

A study of winged helicopter flying and handling qualities requirements, based on the above approach, was conducted under USAAVLABS sponsorship, Contract DA 44-177-AMC-382(T). Based on mission requirements established during the study and available winged helicopter task performance data, recommendations for winged helicopter flying and handling qualities specifications were to be formulated. However, no task performance capability evaluations were made in the winged helicopter test programs conducted up to now. Thus, no relevant flight test data were available, and task performance evaluation techniques were mostly limited to pilot opinion.

In order to generate winged helicopter precision task performance data, and to provide a foundation for development of task performance evaluation techniques, an extensive flight test program specifically designed for this purpose was necessary. A pilot study for such a program was carried out under this contract.

The study was conducted in two parts: (1) the flight test and data collection, and (2) the data processing and data analysis. The flight test tasks performed were:

1. Precision Hover (IGE, OGE)
2. 360° Hovering Turns (OGE)
3. Air Taxi over Prescribed Course
4. Accelerations from Hover to 120 Kn
5. Decelerations from 120 Kn to Hover
6. Figure-8 Turns

External task performance measures were taken for the first three tasks using two specially equipped Automax cameras. Fuselage attitudes, attitude rates, altitude, rate of climb and normal load factor were recorded on board the aircraft using a photo panel and F.M. tape equipment.

The tasks were performed by three pilots, with each pilot performing each task five times to allow evaluation of the statistical significance of the data. The pilots were asked to rate their performance at the end of each trial and the aircraft's task performance capability at the end of each set of five trials.

The data collected were processed by computing a number of summary scores for each measured parameter. These scores were further processed to test the statistical significance of the differences in performance which were found. In addition, power and cross spectral density analyses were computed for evaluation as measures of pilot and vehicle activity.

THE S-61F AIRCRAFT

The S-61F helicopter is a basic S-61 airframe modified into a high-speed compound configuration (Figures 1 through 4). The modifications include a basic drag cleanup, structural strengthening of the aircraft, addition of sponsons to support the J-60 auxiliary propulsion, a fully retractable main landing gear, wings, and oversized horizontal and vertical stabilizers. Both five- and six-bladed main rotors can be fitted to the airframe to investigate solidity effects. No electronic stabilization equipment is used.

DIMENSIONS AND GENERAL DATA

Main Rotor:

Diameter	62 ft
Normal tip speed (100 percent N_R)	660 fps
Disc area	3019 ft^2
Blade chord	18.25 in.
Airfoil section	NACA 0012
Number of blades	6
Solidity	0.0894
Blade twist (center of rotation to tip)	-4 deg
Root cutout (percent span of first blade pocket)	15 pct
Hing offset	1.05 ft
Articulation	Full flapping and lag

Tail Rotor:

Diameter	10 ft 4 in.
Normal tip speed	660 ft/sec
Blade chord	7.34 in.
Airfoil section	NACA 0012
Number of blades	5
Solidity	.188
Blade twist	0 deg
Hinge offset	.323 ft
Articulation	Flapping only
Pitch flap coupling	45 deg

Wing:

Span	32 ft 0 in.
Area	170 ft^2

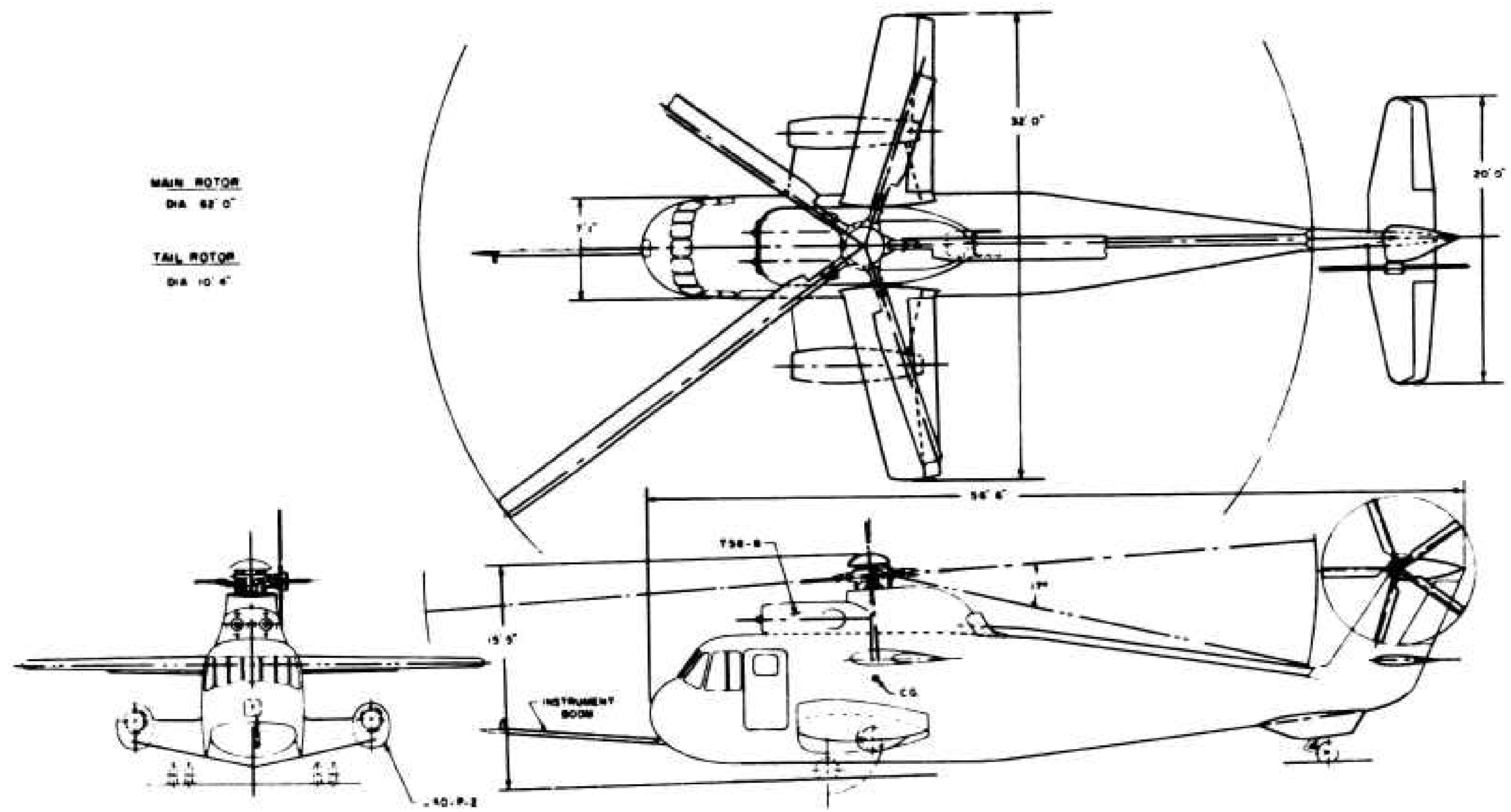


FIGURE 1. S-61F THREE-VIEW, WINGS AND TAIL ON

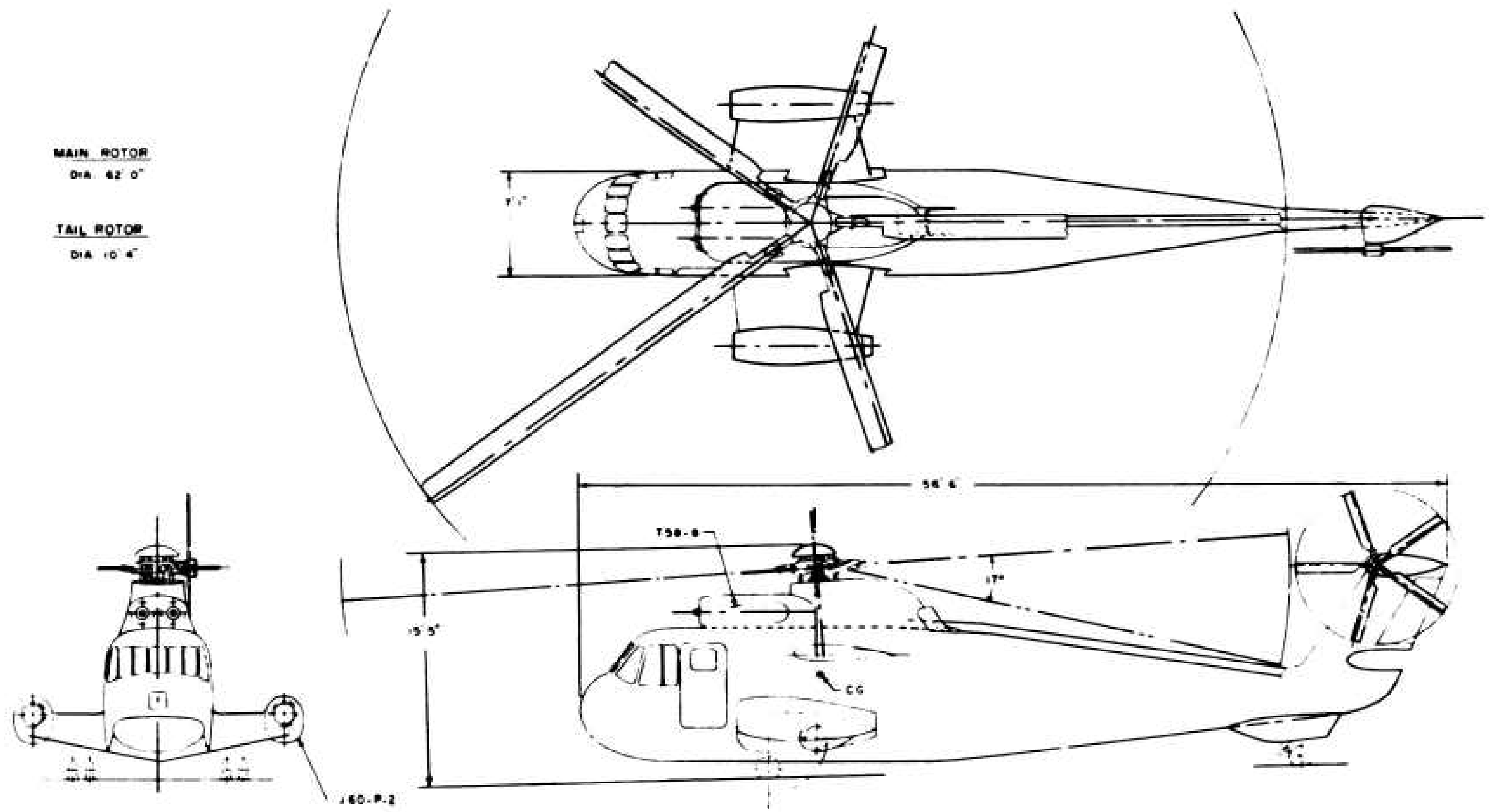


FIGURE 2. S-61F THREE-VIEW, WINGS AND TAIL OFF

FIGURE 3. S-61F WINGS AND TAIL-ON

FIGURE 4. S-61F WINGS AND TAIL-OFF

Exposed area	136.7 ft^2
Taper ratio (tip chord/theo. root chord)	0.5
Tip chord	42.5 in.
Mean aerodynamic chord	72.8 in.
Twist	0 deg
Dihedral	0 deg
Sweep of 25 percent chord line	10 deg
Aspect ratio	6.04
Airfoil section	NACA 63_2 A415
Flap area	29.8 ft^2
Flap chord	25 pct wing chord

Tail Surfaces:

Horizontal tail area	76.2 ft^2
Horizontal tail span	20 ft 0 in.
Elevator area	10.8 ft^2
Horizontal tail airfoil section	NACA 0010 Modified
Vertical tail area (above WL 158)	44 ft^2
Rudder area	8.6 ft^2
Vertical tail airfoil section	NACA 0012 Modified

Fuselage:

Length	56 ft 6 in.
Cabin width	7 ft 1 in.
Landing gear tread	10 ft 0 in.
Wheel base	34 ft 7.5 in.
Rotor head height	15 ft 5.5 in.

Weights (lbs):

Eng. section J-60	343.0
Powerplant group	2,666.4
Fixed equipment group	2,944.7
Weight empty	13,527.1
Useful load	5,472.9
Design gross weight	19,000.0

Powerplants:

Main propulsion unit
Two T-58-GE-8B with following ratings @ SLS:

Ratings:	Power Shaft Output R. P. M.	Max. SFC lbs/SHP/hr
Military rated 1250 SHP	19,500	0.61
Normal rated 1050 SHP	19,500	0.64

Aux propulsion unit
Two J-60-P-2 with following ratings @ SLS:

Ratings:	Jet Thrust lbs (min)	Max. R.P.M.	Max. SFC lbs/hr/lb
Military	2,900	16,400	0.930
Normal	2,570	15,750	0.905

Throughout this program the aircraft was operated at a mid C.G. location (Sta. 273). The hover and air taxi tasks were done at a gross weight of 17,000 pounds, and the accelerations, decelerations and figure-8 turns were done at 18,900 pounds.

OBSERVED FLIGHT CHARACTERISTICS

During preceding tests, such as the Basic Performance Program, the Noise Measurement Survey and the Root Shear Tests, some flying and handling qualities substantially different from those of the basic S-61 helicopter were observed in the S-61F.

The location and size of the horizontal tail produced pitch attitude disturbances in and around the hover flight regime due to variations in rotor downwash impingement with aircraft translation and gusts. These disturbances appeared to make it difficult to maintain steady pitch attitude in and around hover. In addition, the location of the horizontal tail produced excessive pitch attitudes during deceleration flares. The large vertical stabilizer reduced hovering turn rate and the attainable lateral velocity. In forward flight, rotor control power decreases with rotor unloading, and sudden full application of auxiliary thrust can cause pitch control problems due to the location of the J-60 auxiliary propulsion units. The arrangement of engine controls in the cockpit, with the normal throttle controls on the overhead console and the auxiliary propulsion throttles on the center console (Figure 5), makes single pilot power management in maneuvers very difficult.

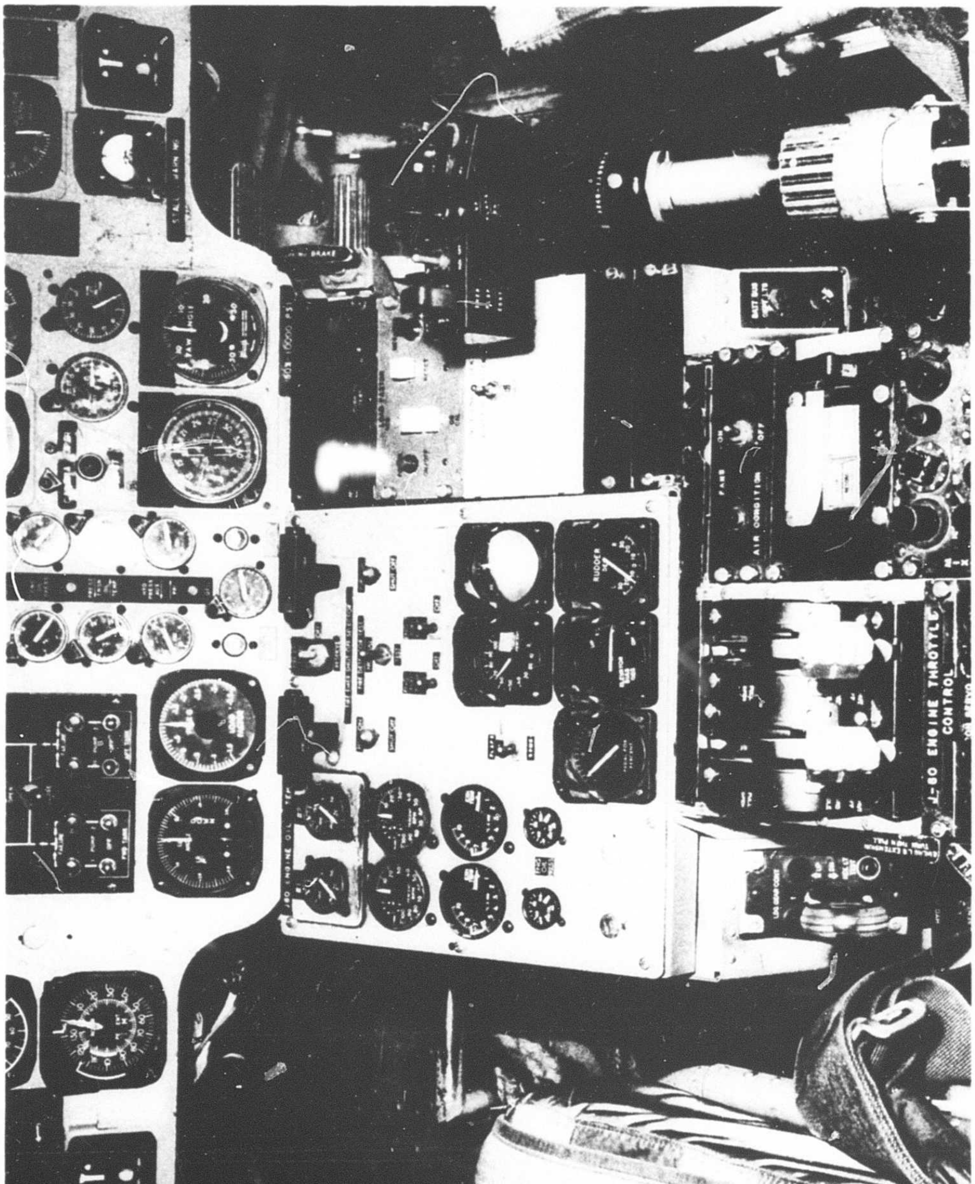


FIGURE 5. COCKPIT THROTTLE CONTROLS

SELECTION AND DESCRIPTION OF TASK

The tasks for this study were selected based on the following criteria:

a. Relevance to potential winged helicopter missions
b. Nonambiguous definition to pilot
c. Measurability of task performance

The relevancy of the task to a potential winged helicopter mission was based upon findings of the winged helicopter flying and handling qualities requirements study, USAAVLABS Contract DA 44-177-AMC-382(T). Tasks in the hover and low-speed flight regime were deemed to be closest to meeting criteria established for task selection. Such tasks as precision hover, hovering turns and precision air taxi are closely related to troop and materials loading and off loading in unprepared sites. These tasks require a minimum time approach and departure, to shorten exposure time; thus, accelerations and decelerations were included as tasks to be performed. Precise control of altitude and airspeed during maneuvering flight was found to be another common requirement in many winged helicopter missions; thus, the constant altitude and airspeed figure-8 turns were included.

Task descriptions were worded in such a way as to preclude any ambiguity, and thus avoid piloting errors in executing the tasks. For example, telling a pilot to keep a particular point on the aircraft over a prescribed spot on the ground while hovering at a 5-foot wheel height with a constant heading defines a task in a way which cannot be misunderstood.

The ability to measure the precision with which a task is being carried out is essential in evaluation of task performance. The preferred task performance evaluation measures are parameters which are to be held constant. Thus, in precision hover such parameters would be longitudinal, lateral and vertical positions and aircraft heading relative to some reference position. Deviations of these parameters from the prescribed values are an indication of task performance error. The tasks chosen and the critical parameters are summarized in Table I.

TASKS

Hover

Hover was performed by attempting to hold the aircraft's rotor head over the intersection of two lines painted on the runway. This was done at a 5-foot wheel height (in ground effect) and at a 50-foot wheel

TABLE I. TASK DESCRIPTION AND CRITICAL PARAMETERS

TASK		CRITICAL PARAMETERS
Hover	IGE	Hold X. Y, Z Position over Line Intersection on Runway. Hold Constant Heading.
	OGE	Hold X, Y, Z Position over Line Intersection on Runway. Hold Constant Heading.
Hovering Turns	Right (IGE)	Hold X, Y, Z Position over Line Intersection on Runway. Make 360° Turn at Max. Rate.
	Left (IGE)	Hold X, Y, Z Position over Line Intersection on Runway. Make 360° Turn at Max. Rate.
Air Taxi	Constant Heading (IGE)	Hold X, Z or Y, Z Position while Tracking Runway Line. Hold Constant Heading.
	Heading along Course (IGE)	Hold Y, Z Position while Tracking Ground Line. Hold Heading along Course.
Figure 8		Hold Constant Altitude and Airspeed while Making 360° Right and Left Turns.
Acceleration		Hold Constant Heading and Altitude while Accelerating from 0 - 120 Knots.
Deceleration		Hold Constant Heading and Altitude while Decelerating from 120 - 0 Knots.

height (out of ground effect). The ground pattern is shown in Figure 6.

Hovering Turns

The 360-degree hovering turns were executed to the right and to the left while attempting to maintain the position of the rotor head over the line intersection painted on the runway. A 5-foot wheel height was to be maintained.

Air Taxi

The air-taxi maneuvers were broken into two parts:

a. Constant heading, which consisted of right sideward, left sideward, forward, and rearward flight with constant heading while maintaining the position of the rotor head over a ground line.
b. Heading along course, in which the aircraft proceeded along a ground course keeping its heading along the desired leg.

In both cases the aircraft was started from a hover, accelerated to 5 knots, and decelerated to a hover at the end of each 100-foot to 150-foot leg before proceeding on the next leg of the course. This was to be done at a wheel height of 5 feet.

These maneuvers were flown over an "L" shaped course painted on the runway. The pilot was instructed to keep the rotor head over the line at all times during the trials.

Acceleration

The maximum performance accelerations were started in a hover over the runway. The J-60 throttles were then advanced to full power. The maneuver was terminated at 120 knots by cutting back the J-60 power and dropping the landing gear. The pilot attempted to hold constant heading and altitude throughout the acceleration.

Deceleration

The deceleration maneuver was performed by making an approach to 30 feet above the runway at 120 knots, chopping the J-60s, dropping the landing gear, and decelerating at maximum rate while holding constant altitude and heading. The maneuver was terminated in a hover.

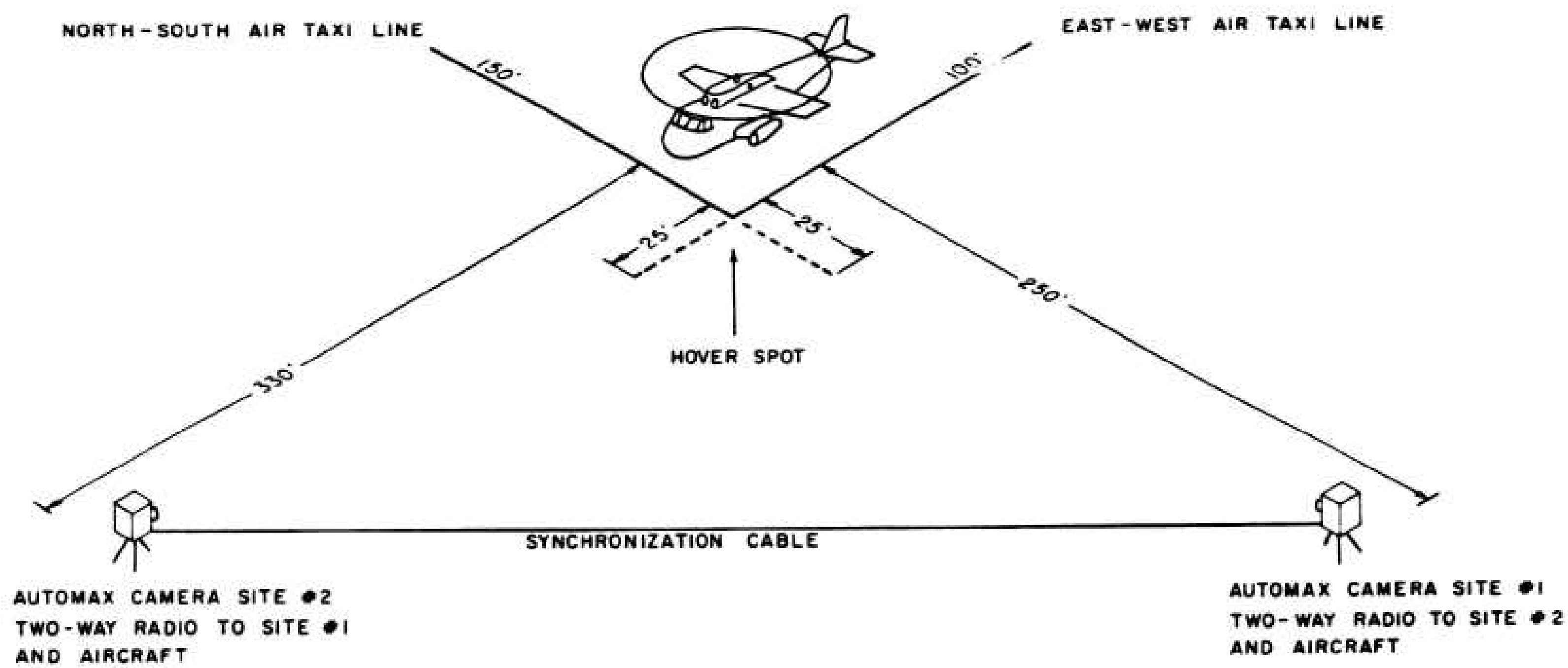


FIGURE 6. GROUND PATTERN OF AIR-TAXI COURSE AND CAMERA SETUP

Figure-8 Turns

The figure-8 maneuvers consisted of two 360-degree turns in opposite directions while holding constant altitude and airspeed. The aircraft was first trimmed at 80 knots without jet thrust; then jet thrust (J-60) was applied, with collective pitch held constant, to bring the aircraft to 100 knots. This speed was to be maintained throughout the turns. The turns were to be entered with maximum acceptable roll rate to maximum tolerable bank angle. Upon completion of the first 360 degrees, the bank angle was reversed at maximum acceptable roll rate.

CONFIGURATION CHANGES

To evaluate the effect of wings and horizontal stabilizer on task performance, each task was performed with two configurations: (1) wings and horizontal tail on, and (2) wings and horizontal tail off. Ideally, half the pilots should fly configuration (1) first, and the other half configuration (2) first. However, since there were only three subject pilots, all tasks for configuration (1) were completed by all pilots, and then they were repeated with configuration (2). This was not considered a factor in the tests because all subject pilots had sufficient time in both the S-61F and the S-61 helicopters to be beyond the point where learning effects are significant.

INSTRUMENTATION AND DATA COLLECTION SYSTEM

Instrumentation and a data collection system for both objective and subjective task performance evaluation were developed for this study. The objective task performance measures were collected using on-board equipment and specially designed ground-based movie cameras. On-board equipment consisted of instrumentation, a photo panel and an F.M. tape recorder. These were operated by a flight engineer, who also collected pilot opinion data and timed the trials. The collected data included task performance precision, pilot work load (control activity), and pilot opinion. The objective data collection system was designed to eliminate the need for detailed manual analysis of oscillograph records, and to provide a convenient means of data processing by computer. Subjective ratings of task performance were taken after each trial, with a rating of aircraft suitability for the task being recorded at the end of each five-trial set.

CAMERA DATA

The hover and air-taxi tasks were carried out at the Sikorsky flight field. An "L" shaped pattern was painted on the field and used as a reference during these tests. Dashed extensions of the two lines were drawn beyond the apex of the pattern to be used as references when the pilot was not facing the pattern. Hovers and hovering turns were performed over the apex of the pattern, as shown in Figure 6. Air-taxi maneuvers were flown along the pattern, with stops at the end of each segment, thus permitting the use of an "L" pattern instead of a rectangle. Two camera sites were selected so that each camera was aimed along one line of the pattern to record the aircraft's deviation from the line.

The cameras used in this program to photograph the aircraft were Automax cameras with a grid etched on the lens and a photo panel mounted to the camera, Figure 7. The photo panel for this program contained a timer, a frame counter and a card marked with the flight and trial numbers. The cameras were connected by a synchronization cable and triggered simultaneously at 1-second intervals during data recording. Four timing lights were mounted on the aircraft, one on each J-60 nacelle, one on the nose and one on the tail. These lights, operated from on board the aircraft, were turned on at the beginning and turned off at the end of each trial. This gives a convenient means of identifying the start and finish of each trial on the camera data. The trial number was marked on the photo panel before each trial by the camera operator, who also ran off some blank film to separate the trials. The cameras were started before each trial to bring them up to record the instant the lights went on at the start of the trial.

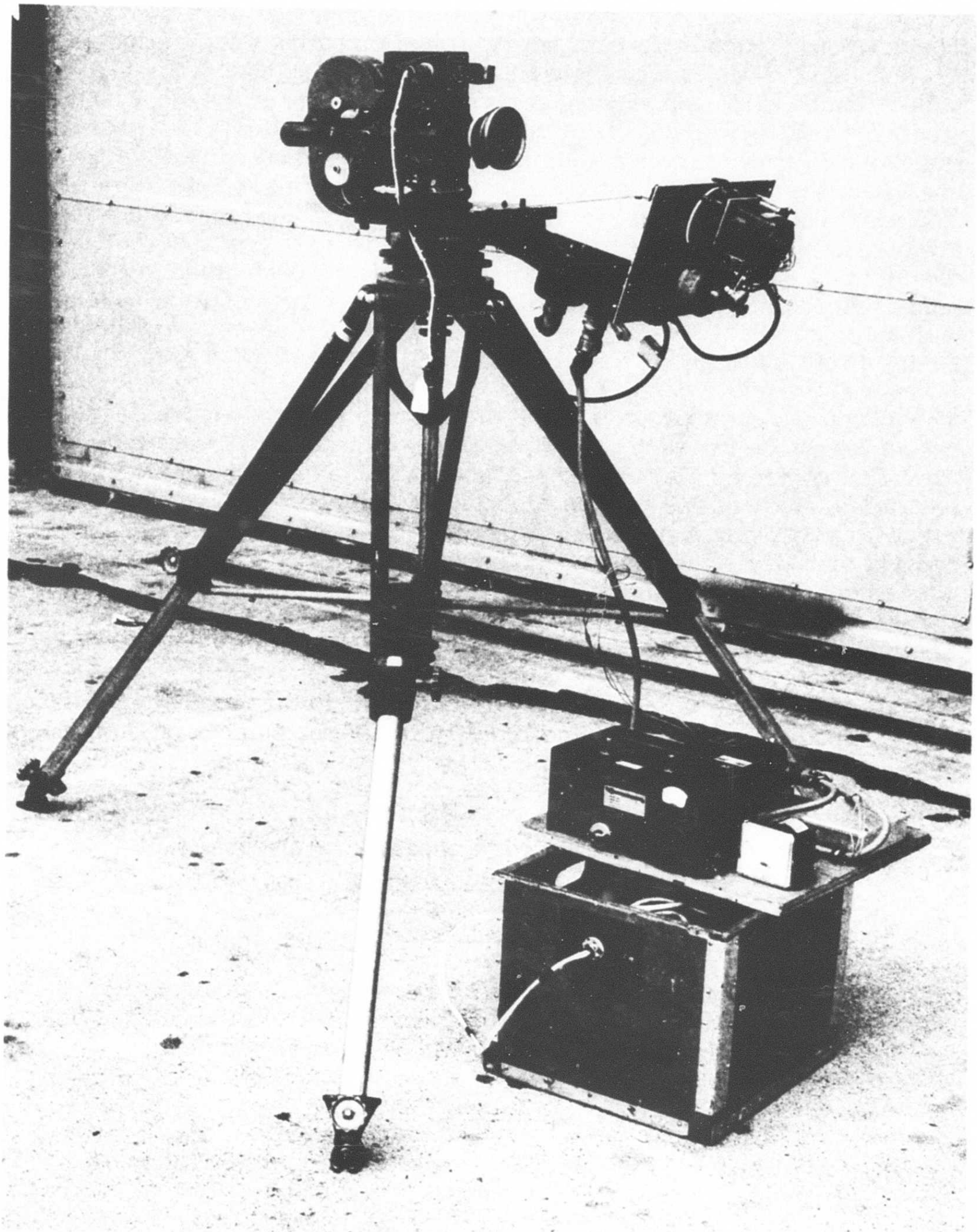


FIGURE 7. THE AUTOMAX CAMERA

The developed films were read with a Tele-Computing Corporation "Telereadex" film reader, Figure 8. This device projects the picture onto a table-top viewing screen, Figure 9. The operator positions a set of cross hairs over the selected reference point on the aircraft and presses a foot switch which automatically records the aircraft's coordinates on an I. B. M. card and advances the film to the next frame. The rotor hub was used as the aircraft reference point because it was always visible from both camera sites and because it was specified to the pilots as the reference point for the maneuvers performed in this study. At the beginning of each film, a number of frames were taken with an object placed at the apex of the "L" shaped curve to provide a position reference for the rest of the film.

The use of two cameras gave two I. B. M. cards with the aircraft's coordinates, one for each camera location. These cards were processed through a computer program to produce a time history of the aircraft's position in space. These were processed further by the computer program to provide numerical summary values which were used in subsequent statistical analyses. The following data were calculated and printed out on a trial data summary sheet, Figure 10.

The task performance measures calculated were as follows:

a. Mean Position Error - Calculated by summing the deviation from the desired point or line and dividing by the number of samples.

$$\bar{X}_{position} = \frac{\Sigma(X_{desired} - X_{actual})}{\text{Number of Samples}}$$

b. Standard Deviation - This is a measure of dispersion of a distribution and was computed as follows:

$$\sigma = \sqrt{\frac{\Sigma(X_{actual} - \bar{X})^2}{\text{Number of Samples} - 1}}$$

c. Average Integrated Absolute Error - This is calculated by taking the absolute values of the deviation from the desired point, summing these and dividing by the number of samples.

$$\bar{X}_{absolute} = \frac{\Sigma|X_{desired} - X_{actual}|}{\text{Number of Samples}}$$

d. RMS Error - This was calculated according to the following formula:

$$X_{RMS} = \sqrt{\frac{\Sigma(X_{desired} - X_{actual})^2}{\text{Number of Samples}}}$$

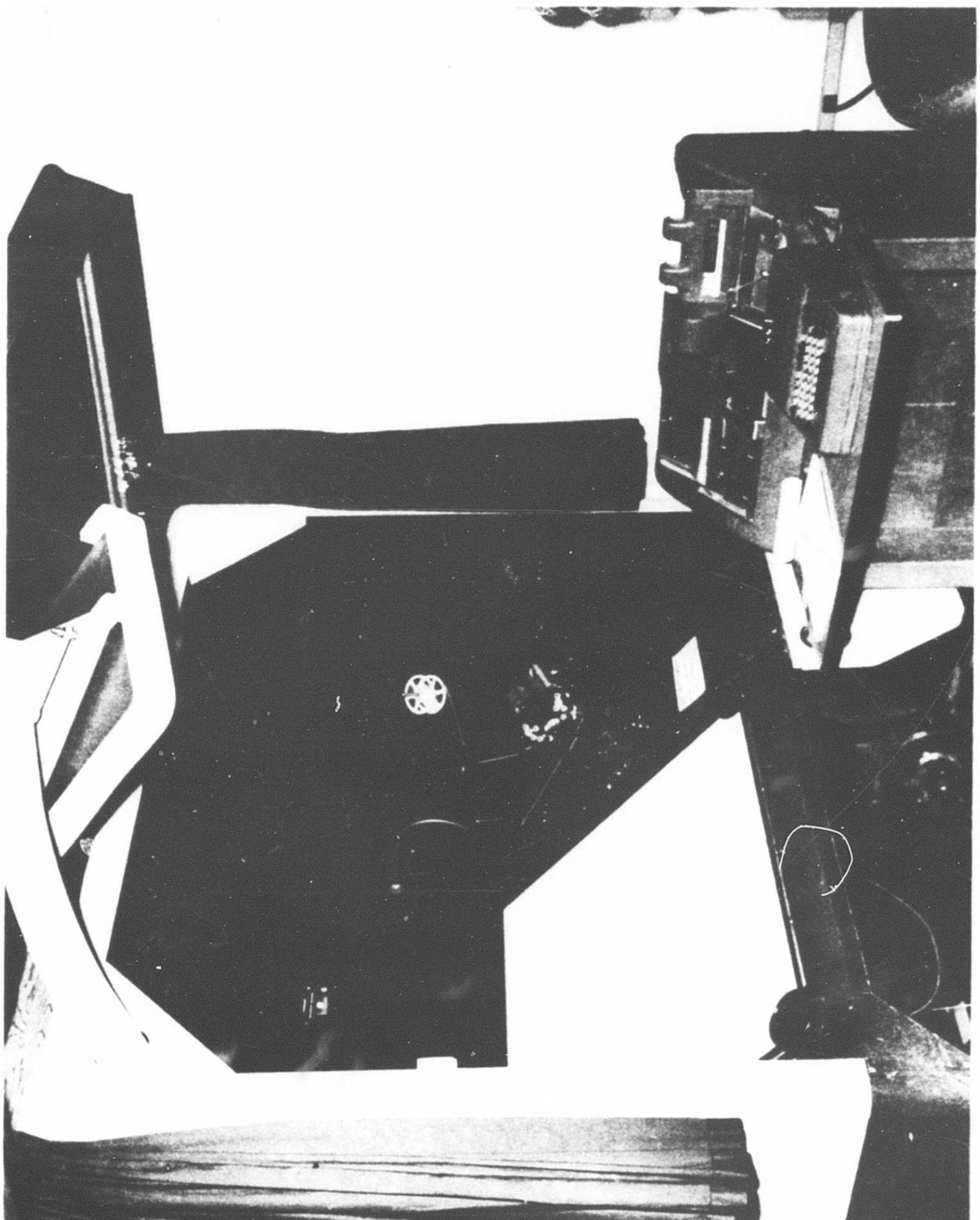


FIGURE 8. "TELEREADEX" MACHINE

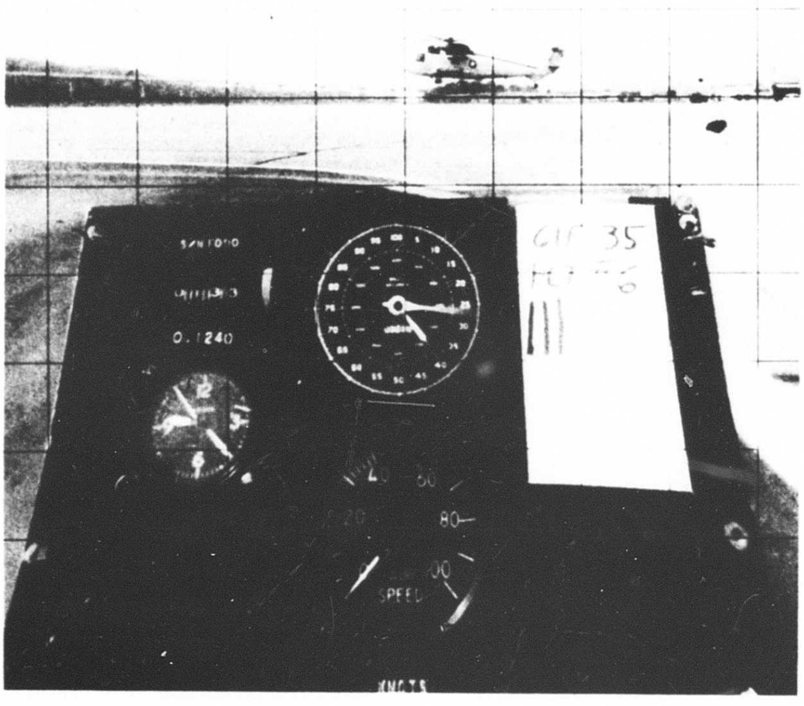


FIGURE 9. PICTURE SEEN ON "TELEREADEX" SCREEN

PAGE NO.............
REPORT NO...........
TABLE NO............

WINGS AND HORIZONTAL STABILIZER ON
AUTOMAX CAMERA DATA
OUT OF GROUND EFFECT HOVER

G.W. 17000. FLIGHT 10
C.G. 273.0 PILOT 3
DATE 8/29/67 TRIAL 5

PRIMARY CAMERA 2

	MEAN POSITION ERROR	STANDARD DEVIATION	INTEGRATED ABSOLUTE ERROR	AVERAGE ABSOLUTE ERROR	INTEGRATED ERROR SQUARED	RMS ERROR	MIN ERROR	MAX ERROR	OFFSET BASED ERROR
LONG. POS.	2.1580	2.1249	154.1232	2.4082	582.5045	3.0169	-.9903	5.8758	2.7011
LAT. POS.	3.8186	4.2532	313.4211	4.8972	2072.8578	5.6911	-5.1230	11.6762	3.8146
VERT. POS.	-.2496	1.5184	82.9209	1.2956	149.2374	1.5270	-2.4922	2.7893	

LONG. POS. ERROR	LONG. POS. %	LAT. POS. ERROR	LAT. POS. %	VERT. POS. ERROR	VERT. POS. %
-10.	.00	-10.	.00	-10.	.00
-9.	.00	-9.	.00	-9.	.00
-8.	.00	-8.	.00	-8.	.00
-7.	.00	-7.	.00	-7.	.00
-6.	.00	-6.	.00	-6.	.00
-5.	.00	-5.	4.69	-5.	.00
-4.	.00	-4.	4.69	-4.	.00
-3.	.00	-3.	.00	-3.	.00
-2.	.00	-2.	4.69	-2.	25.00
-1.	14.06	-1.	3.13	-1.	25.00
-0.	15.63	-0.	3.13	-0.	23.44
1.	14.06	1.	4.69	1.	9.38
2.	7.81	2.	15.63	2.	10.94
3.	15.63	3.	4.69	3.	6.25
4.	14.06	4.	6.25	4.	.00
5.	14.06	5.	7.81	5.	.00
6.	4.69	6.	12.50	6.	.00
7.	.00	7.	4.69	7.	.00
8.	.00	8.	9.38	8.	.00
9.	.00	9.	4.69	9.	.00
10.	.00	10.	9.38	10.	.00

FIGURE 10. CAMERA DATA SUMMARY SHEET

e. Peak Errors - This measure simply recorded the high and low end points of the distribution.

f. Offset Based Error - This measure was employed to measure the error from the initial point of the time history. The computation formula was as follows:

$$\bar{X}_{offset} = \frac{\Sigma |X_{initial} - X_{actual}|}{\text{Number of Samples}}$$

g. Distribution Printouts - In addition to the above scores, the program printed the distribution of error in tabular form showing the percentage of time spent in each of ±10 one-foot intervals from the desired value.

ON-BOARD DATA COLLECTION AND ANALYSIS

In order to generate the data necessary for development of task performance evaluation techniques, an on-board data acquisition system was designed to supplement the ground-based Automax cameras. This system recorded such parameters as aircraft accelerations, vibrations, attitudes, attitude rates, control positions, etc., as shown in Table II.

Equipment Used

The primary recording device was an AR-200 narrow band F.M. (I. R. I. G.) Magnetic Tape Recorder with associated signal conditioning equipment and transducers. The quasi-static data were recorded on 35-mm film using a six-hole photo panel.

Location of Equipment

The AR-200 Tape Recorder equipment was located primarily in the cabin area, forward of the aircraft center of gravity. The photo panel was on the port side of the aircraft center of gravity. The four external lights provided on the aircraft to synchronize the two ground cameras were located on each of the J-60 nacelles, on the aircraft nose, and on the aircraft stabilizer.

Description of Recording Equipment

Dynamic data were recorded on two tracks of a 14-track AR-200 N. B. F. M. (I. R. I. G.) Magnetic Tape Recorder (10 measurements per track). Signal conditioning was provided by bridge balancing modules for the adjustment of bridge balance and sensitivity. A block diagram of the Magnetic Tape System is shown in Figures 11 and 12.

TABLE II. TABLE OF MEASUREMENTS

Item	Parameter	Transducer	Location	Range	Accuracy
		MAGNETIC TAPE			
1	Longitudinal Stick Position	Potentiometer	Azimuth Stick	0-100%	±1%
2	Lateral Stick Position	Potentiometer	Azimuth Stick	0-100%	±1%
3	Collective Stick Position	Potentiometer	Collective Stick	0-100%	±1%
4	Rudder Pedal Position	Potentiometer	Rudder Pedals	0-100%	±1%
5	#1 J-60 Throttle Position	Potentiometer	J-60 Throttle	0-100%	±1%
6	#2 J-60 Throttle Position	Potentiometer	J-60 Throttle	0-100%	±1%
7	Pitch Attitude	Vert. Att. Gyro	Aircraft Cabin	±20°	±1°
8	Roll Attitude	Vert. Att. Gyro	Aircraft Cabin	±40°	±1°
9	Yaw Attitude	Long. Att. Gyro	Aircraft Cabin	±180°	±1°
10	Pitch Rate	Rate Gyro	Aircraft Cabin	±30°/sec	±1°/sec
11	Roll Rate	Rate Gyro	Aircraft Cabin	±30°/sec	±1°/sec
12	Yaw Rate	Rate Gyro	Aircraft Cabin	±30°/sec	±1°/sec
13	Vertical Load Factor Acc.	Linear Accel.	Center of Gravity	±3g's	±2%
14	Vertical Load Factor Acc.	Linear Accel.	Pilot Station	±3g's	±2%
15	Longitudinal Load Factor Acc.	Linear Accel.	Pilot Station	±3g's	±2%
16	Lateral Load Factor Acc.	Linear Accel.	Pilot Station	±3g's	±2%
17	Vertical Linear Acc.	Linear Accel.	Pilot Station	±5g's	±2%
18	Longitudinal Linear Acc.	Linear Accel.	Pilot Station	±5g's	±2%
19	Lateral Linear Acc.	Linear Accel.	Pilot Station	±5g's	±2%
		PHOTOPANEL			
1	Altimeter	A/C Pitot Tube	Photopanel	0-5,000 ft.	
2	Airspeed	A/C Pitot Tube	Photopanel	0-200 kts.	
3	Rate of Climb	A/C Pitot Tube	Photopanel	±3000 ft/min	
4	M. R. RPM	Tach Generator	Photopanel	0-110%	
5	O. A. T.	Resistance Bulb	Photopanel	±30°C	
6	Magnetic Compass	A/C Radio Compass	Photopanel	------	
7	Run Counter	---------------	Photopanel	5 digits	
8	Frame Counter	---------------	Photopanel	5 digits	
9	Clock	---------------	Photopanel	8 day	

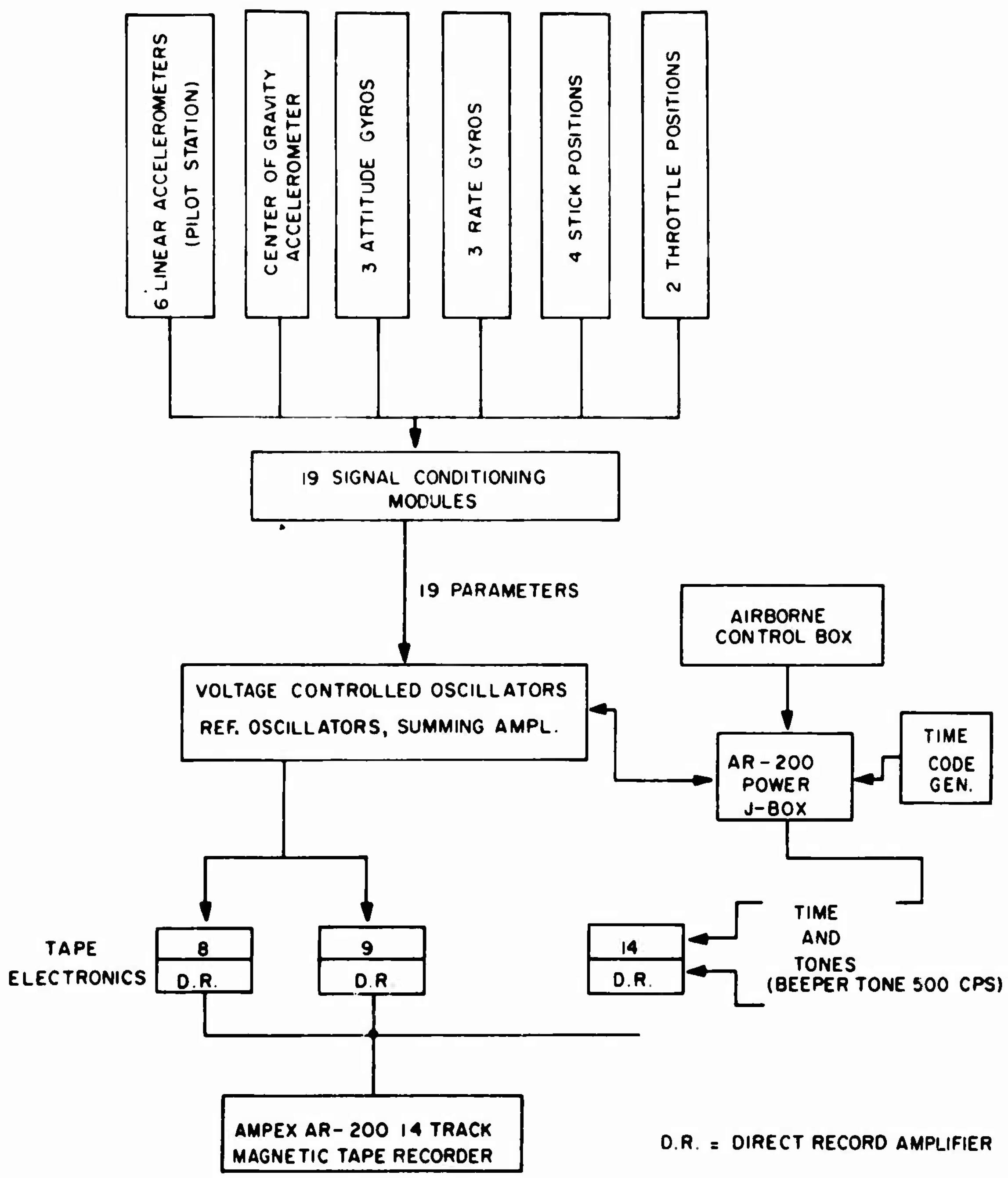


FIGURE 11. BLOCK DIAGRAM OF AIRBORNE MAGNETIC TAPE RECORDING SYSTEM

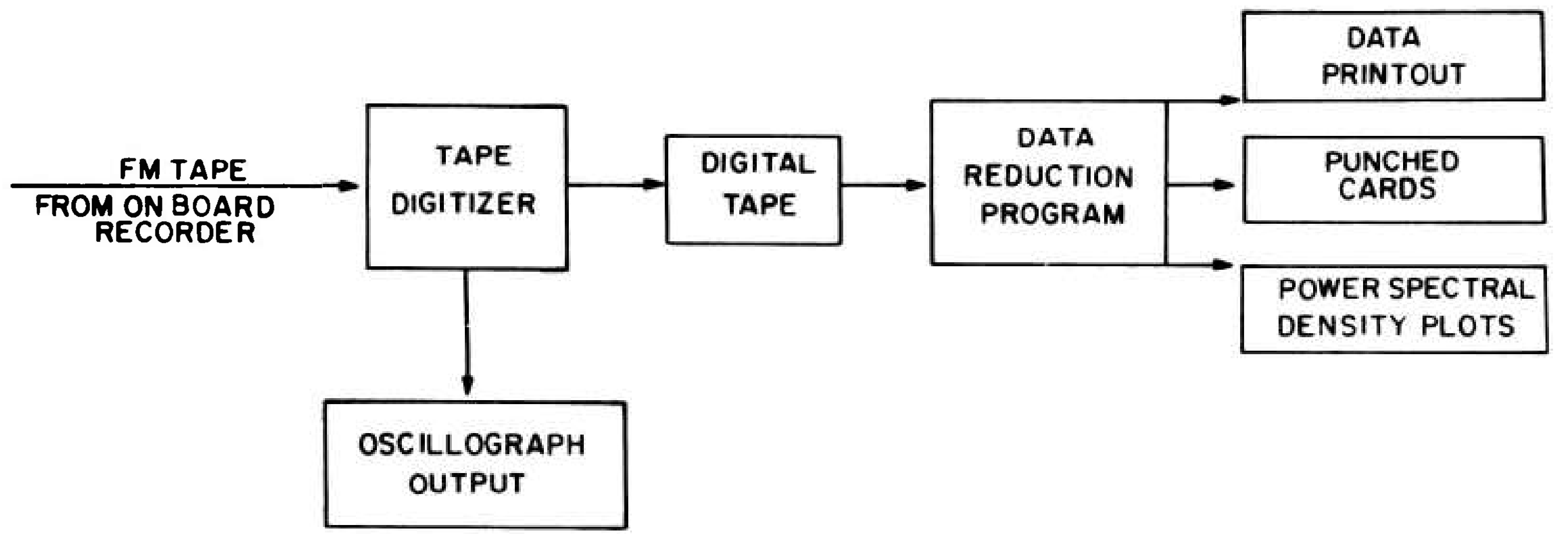


FIGURE 12. BLOCK DIAGRAM OF GROUND-BASED TAPE DATA REDUCTION SYSTEM

Quasi-static data were recorded on 35-mm film using standard photo-panel techniques. Instrumentation lighting was provided by flash units synchronized with the shutter opening. A block diagram of the photo panel instrumentation is shown in Figure 13.

Time correlation between the photo panel, magnetic tape and the two ground cameras was provided by a 500 cps "beeper" tone signal. This signal was recorded on the magnetic tape whenever the photo panel event marker light and the four external camera lights were switched on and the photo panel was recording.

Calibration

Physical calibrations of all items were made prior to installation in the aircraft, with system zero and sensitivity calibrations being performed before and after each flight.

Standard Sikorsky calibration procedures were employed with laboratory reference standards traceable to N. B. S. In cases where drift was noted on a given parameter at the end of a flight, the parameter in question was dropped from subsequent analysis.

Data Processing

The photo-panel data reduction was performed at the Flight Operation Facilities, where the films were developed and read and the data put on I. B. M. cards for processing.

The F. M. tapes taken during the flight were converted to a digital format at the Sikorsky Tape and Telemetry Data Processing Ground Station. Simultaneous with the conversion, an oscillograph record of the tape data was run for visual checking. The digitized tapes were then run through a computer program similar to the one used with Automax film data, but with several additional measures for control and aircraft attitude activity evaluation. Sample printouts are shown in Figures 14 and 15.

The additional measures were as follows:

a. Average Integrated Absolute Position - Was calculated primarily as an indication of the average displacement of the control from its mean position. The following formula was used for this calculation:

$$\bar{X}_{displ.} = \frac{\Sigma |X_{actual} - \bar{X}|}{n}$$

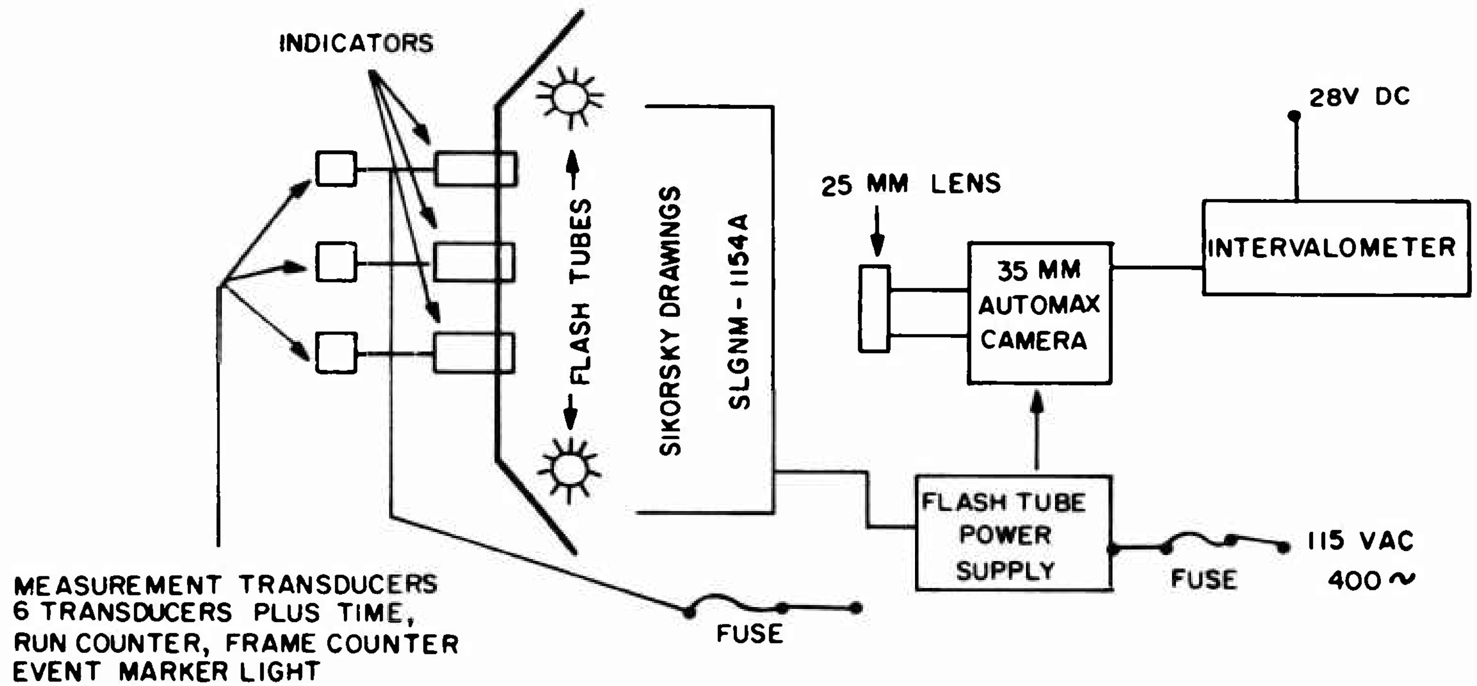


FIGURE 13. BLOCK DIAGRAM OF PHOTO PANEL

PAGE NO. ....
REPORT NO. ....
TABLE NO. ....

IN GROUND EFFECT HOVER
WINGS AND HORIZONTAL STABILIZER ON
TAPE RECORDED DATA

G.W. 17000 FLIGHT NO. 5
C.G. 273. PILOT NO. 1
DATE 8/ 3/67 TRIAL 1

DEG	YAW ATTITUDE	DEG/SEC	YAW RATE	%	LONGITUDINAL STICK	LATERAL STICK	COLLECTIVE	PEDALS
-10	.0	-20	.0	30	.0	.0	.0	.0
-9	.0	-18	.0	32	.0	.0	.0	.0
-8	.0	-16	.0	34	.0	.0	.0	1.6
-7	.0	-14	.0	36	.0	.0	.0	19.7
-6	.0	-12	.0	38	.0	.0	.0	30.1
-5	.0	-10	.0	40	.0	.0	.0	25.4
-4	.0	-8	.0	42	1.7	.0	.0	21.1
-3	.0	-6	.0	44	3.6	2.4	.0	2.2
-2	.0	-4	.0	46	38.2	20.9	.0	.0
-1	.0	-2	11.6	48	27.5	46.8	.0	.0
0	2.4	0	71.7	50	20.0	27.5	.0	.0
1	.0	2	16.6	52	7.9	2.4	.0	.0
2	18.1	4	.0	54	.7	.0	42.0	.0
3	.0	6	.0	56	.3	.0	58.0	.0
4	36.7	8	.0	58	.0	.0	.0	.0
5	35.9	10	.0	60	.0	.0	.0	.0
6	.0	12	.0	62	.0	.0	.0	.0
7	4.8	14	.0	64	.0	.0	.0	.0
8	.0	16	.0	66	.0	.0	.0	.0
9	.0	18	.0	68	.0	.0	.0	.0
10	.0	20	.0	70	.0	.0	.0	.0

	STICK CROSSES MEAN	STICK CHANGES RATE SIGN	STICK MOVES SLOWER THAN .5 PERCENT/SEC
LONGITUDE STICK	10.7	21.6	69.9
LATERAL STICK	10.2	16.4	71.2
COLLECTIVE	14.0	15.0	91.2
PEDALS	5.2	8.6	82.7

FIGURE 14. SAMPLE F.M. TAPE DATA PRINTOUT

PAGE NO. ....
REPORT NO. ....
TABLE NO. ....

IN GROUND EFFECT HOVER
WINGS AND HORIZONTAL STABILIZER ON
TAPE RECORDED DATA

G.W. 17000 FLIGHT NO. 5
C.G. 273. PILOT NO. 1
DATE 8/ 3/67 TRIAL 1

	MEAN POSITION ERROR	STANDARD DEVIATION	INTEGRATED ABSOLUTE ERROR	AVERAGE INT. ERROR	INT. ERROR SQUARED	RMS ERROR	PEAK VALUES MAX	PEAK VALUES MIN	INT. ABSOLUTE POSITION	AVERAGE INT. POSITION	INTEGRATED ABSOLUTE RATE	AVERAGE INT. RATE
ROLL ATTITUDE	-3.131	.759	1813.	3.131	.60+04	3.221	-.7	-4.8	360.	.62	755.85	1.31
PITCH ATTITUDE	5.836	.611	3379.	5.836	.20+05	5.868	7.3	4.6	286.	.49	435.49	.75
YAW	4.401	1.386	2548.	4.401	.12+05	4.614	7.2	.9	661.	1.14	636.39	1.10
ROLL RATE	-.167	1.238	583.	1.007	.90+03	1.248	3.3	-3.1	585.	1.01	1499.23	2.59
PITCH RATE	-.006	.782	349.	.604	.35+03	.781	2.6	-2.0	349.	.60	845.94	1.46
YAW RATE	.114	.807	391.	.675	.38+03	.815	2.5	-1.9	383.	.66	791.69	1.37
LONGITUDE STICK	46.766	2.167	27077.	46.766	.13+07	46.816	54.6	40.1	982.	1.70	3317.52	5.73
LATERAL STICK	47.098	1.515	27270.	47.098	.13+07	47.122	50.3	43.0	704.	1.22	2244.07	3.88
COLLECTIVE	54.094	.365	31320.	54.094	.17+07	54.095	55.3	53.2	182.	.31	547.75	.95
PEDALS	37.962	2.083	21980.	37.962	.84+06	38.019	42.5	33.9	1014.	1.75	1478.26	2.55

FIGURE 15. SAMPLE F.M. TAPE DATA ANALYSIS PRINTOUT

b. Average Integrated Rate - This was calculated according to the following formula to serve as a measure of the average rate at which the controls were moved.

$$\bar{\dot{X}}_{Abs} = \frac{\Sigma \; |\dot{X}_{act} - \bar{\dot{X}}_{des}|}{n}$$

c. Steady Control Time - This measure indicated the percentage of trial time during which the control was moved at a rate lower than .5% total travel per second.

d. Control Crossovers - A count was made of the number of times the control crossed its mean position per second.

e. Control Rate Sign Changes - A count was made of the number of times the control rate changed signs per second.

f. Power and Cross Spectral Density Analysis - These techniques were applied to determine the frequency content of the control activity and the aircraft attitude activity.

PILOT OPINION DATA

In addition to the objective measures of system performance and pilot work load, pilot opinion ratings were taken using the new Cooper-Harper rating scale and two five-point scales developed by Bunker Ramo under Air Force contract.

The Cooper-Harper ratings (Figure 16) were taken after each block of five trials. Each pilot rated each configuration (wing and tail on and off) for hover, air taxi, acceleration, deceleration and figure-8 turns. This resulted in a total of 10 ratings of this type from each pilot.

It was felt that a separate scaling system was necessary to measure the trial by changes in the pilot's feelings toward the aircraft's flying qualities. The Cooper scale does not lend itself well to this application because it is intended as an aircraft rating rather than a performance rating. A pilot who prides himself on consistency tends to make this rating a stable value from trial to trial. Therefore, two five-point scales, one for pilot rating of task performance and the second for pilot rating of work load, were utilized to reflect differences in performance and work load among trials. These scales are shown in Figure 17. The flight test engineer asked the pilot for ratings on these scales after each trial. In addition, the pilot was asked to comment on any gusts which he felt during the trial.

<table>
<tr>
<td rowspan="9">CONTROLLABLE
CAPABLE OF BEING CONTROLLED OR MANAGED IN CONTEXT OF MISSION, WITH AVAILABLE PILOT ATTENTION</td>
<td rowspan="6">ACCEPTABLE
MAY HAVE DEFICIENCIES WHICH WARRANT IMPROVEMENT, BUT ADEQUATE FOR MISSION.
PILOT COMPENSATION, IF REQUIRED TO ACHIEVE ACCEPTABLE PERFORMANCE, IS FEASIBLE.</td>
<td rowspan="3">SATISFACTORY
MEETS ALL REQUIREMENTS AND EXPECTATIONS, GOOD ENOUGH WITHOUT IMPROVEMENT
CLEARLY ADEQUATE FOR MISSION.</td>
<td>EXCELLENT, HIGHLY DESIRABLE</td>
<td>A1</td>
</tr>
<tr>
<td>GOOD, PLEASANT, WELL BEHAVED</td>
<td>A2</td>
</tr>
<tr>
<td>FAIR. SOME MILDLY UNPLEASANT CHARACTERISTICS. GOOD ENOUGH FOR MISSION WITHOUT IMPROVEMENT.</td>
<td>A3</td>
</tr>
<tr>
<td rowspan="3">UNSATISFACTORY
RELUCTANTLY ACCEPTABLE. DEFICIENCIES WHICH WARRANT IMPROVEMENT. PERFORMANCE ADEQUATE FOR MISSION WITH FEASIBLE PILOT COMPENSATION.</td>
<td>SOME MINOR BUT ANNOYING DEFICIENCIES. IMPROVEMENT IS REQUESTED. EFFECT ON PERFORMANCE IS EASILY COMPENSATED FOR BY PILOT.</td>
<td>A4</td>
</tr>
<tr>
<td>MODERATELY OBJECTIONABLE DEFICIENCIES. IMPROVEMENT IS NEEDED. REASONABLE PERFORMANCE REQUIRES CONSIDERABLE PILOT COMPENSATION.</td>
<td>A5</td>
</tr>
<tr>
<td>VERY OBJECTIONABLE DEFICIENCIES. MAJOR IMPROVEMENTS ARE NEEDED. REQUIRES BEST AVAILABLE PILOT COMPENSATION TO ACHIEVE ACCEPTABLE PERFORMANCE.</td>
<td>A6</td>
</tr>
<tr>
<td rowspan="3">UNACCEPTABLE
DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT. INADEQUATE PERFORMANCE FOR MISSION EVEN WITH MAXIMUM FEASIBLE PILOT COMPENSATION.</td>
<td rowspan="3"></td>
<td>MAJOR DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT FOR ACCEPTANCE. CONTROLLABLE. PERFORMANCE INADEQUATE FOR MISSION, OR PILOT COMPENSATION REQUIRED FOR MINIMUM ACCEPTABLE PERFORMANCE IN MISSION IS TOO HIGH.</td>
<td>U7</td>
</tr>
<tr>
<td>CONTROLLABLE WITH DIFFICULTY. REQUIRES SUBSTANTIAL PILOT SKILL AND ATTENTION TO RETAIN CONTROL AND CONTINUE MISSION.</td>
<td>U8</td>
</tr>
<tr>
<td>MARGINALLY CONTROLLABLE IN MISSION. REQUIRES MAXIMUM AVAILABLE PILOT SKILL AND ATTENTION TO RETAIN CONTROL.</td>
<td>U9</td>
</tr>
<tr>
<td colspan="3">UNCONTROLLABLE
CONTROL WILL BE LOST DURING SOME PORTION OF MISSION.</td>
<td>UNCONTROLLABLE IN MISSION.</td>
<td>10</td>
</tr>
</table>

FIGURE 16. COOPER-HARPER RATING SCALE

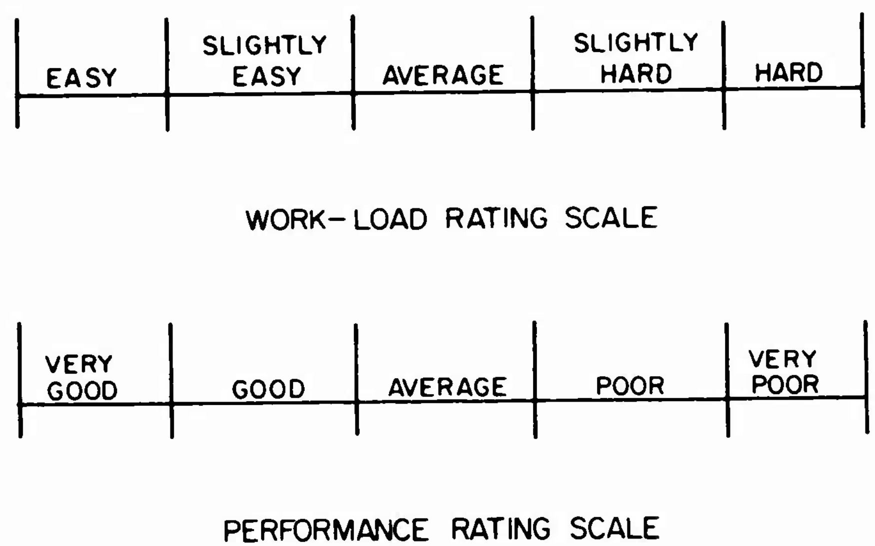


FIGURE 17. PILOT WORKLOAD AND PERFORMANCE RATING SCALES

SUBJECTS

Three Sikorsky experimental test pilots served as subjects for this study. All three had been previously checked out in the S-61F and had flown it in previous programs. In addition, all had experience in the basic S-61 series and other Sikorsky helicopters. Their experience is summarized in Table III.

Each of these pilots completed the entire program. All pilots flew identical conditions so that individual differences in performance would not obscure the differences due to changes in aircraft configuration.

TABLE III. PILOT EXPERIENCE (HOURS LOGGED)

PILOT	S-61F Pilot	S-61F Copilot	Other S-61 Types	Total Helicopter	Total Fixed Wing
1	14:48	1:12	526:58	3048:21	1322:30
2	48:24	---	829:18	3318:32	1425:19
3	16:00	1:30	1292:56	3668:14	947:25

RESULTS

GENERAL DISCUSSION

The data generated in this program are summarized in a form which facilitates the evaluation of wing and horizontal tail influence on precision task performance and the development of task performance evaluation techniques. Three types of data are presented for the tasks: (1) performance precision, (2) pilot work load, and (3) pilot opinion. Standard data analysis was performed for each task, with the addition of a comprehensive analysis of interrelationships among the measures for the hover tasks.

Extensive use is made of isometric figures to graphically represent the task performance errors along the axes where they occurred. It should be noted that the scales of the isometric figures vary from figure to figure to suit the dimensions of each type of data, and thus do not match the scale of the helicopter figures.

At the end of each section there is a table which shows the results of the analyses of variance which were applied to test the statistical significance of the measured differences. In these tables an "x" is placed where a parameter meets the commonly accepted criterion of significance ($p < .05$) and an "n. s." is placed where the difference is nonsignificant. A discussion of these statistical tests is found in Appendix I.

Each of these tables is organized so that the parameters tested are listed along the left-hand column while the columns to the right indicate the type of comparison being tested. For example, if we were to look at the parameter longitudinal offset error, an "x" would appear in each column where configuration (wing and tail on vs. wing and tail off), height (IGE vs. OGE), pilot differences, or interactions of these parameters was found to produce a statistically significant effect on the data. Where "n. s." appears, the analysis indicated that differences were not significant.

HOVER

Objective Data

Figures 18 through 22 summarize the precision with which the hover was performed. The isometric diagrams show the objective measures of aircraft performance taken from the synchronized cameras. Out of ground effect (OGE) and in ground effect (IGE) conditions are represented by the upper and lower blocks respectively. The attitudes were 50 feet for out of ground effect and 5 feet for in ground effect conditions. In addition, the left-hand blocks represent the wing-and-tail-on and the right-hand figures represent the wing-and-tail-off configurations.

Average Absolute Error

Figure 18 shows the average absolute error measured between the aircraft reference point and the desired point on the ground. These data do not include vertical error because the pilot had no exact reference for either the 5- or 50-foot altitudes. In general, it is possible to see that the IGE rectangles are smaller than the OGE rectangles. The major contributing factor to these errors was the initial mispositioning of the rotor head relative to the ground reference point. This was caused by the pilot's uncertainty about how far behind him the rotor head was and the exact location of the ground reference point beneath him. This type of error is not attributable to vehicle dynamics and was therefore modified by assuming that the initial position chosen by the pilot was the point he tried to hold. This measure we have called offset error.

Offset Error

Figure 19 shows the results of using the initial hover point chosen by the pilot as the error reference point. In this case the vertical dimension is included since the pilot's initial choice of altitude was used as an altitude error reference. The heading error shown was calculated in the same manner as the displacements. Table IV shows the analyses of variance results for these data. The effect of configuration produced significant differences only for the lateral and heading measures and not for vertical or longitudinal. The IGE vs. OGE comparison produced significant differences for all measures except heading. The most striking differences are between the high and low hovers, with the low hover producing much more accurate performance.

Standard Deviation

The standard deviation data shown in Figure 20 represent 2σ values. For a normal distribution, this represents the range where 68% of the samples fall. The larger the value, the more dispersion of position. The block shapes are quite similar to those in the previous figure. Aircraft configuration produces significant differences in longitudinal and lateral error, with longitudinal being better in the wing-and-tail-on configuration and lateral being better in the wing-and-tail-off condition. Vertical dispersion did not differ significantly with

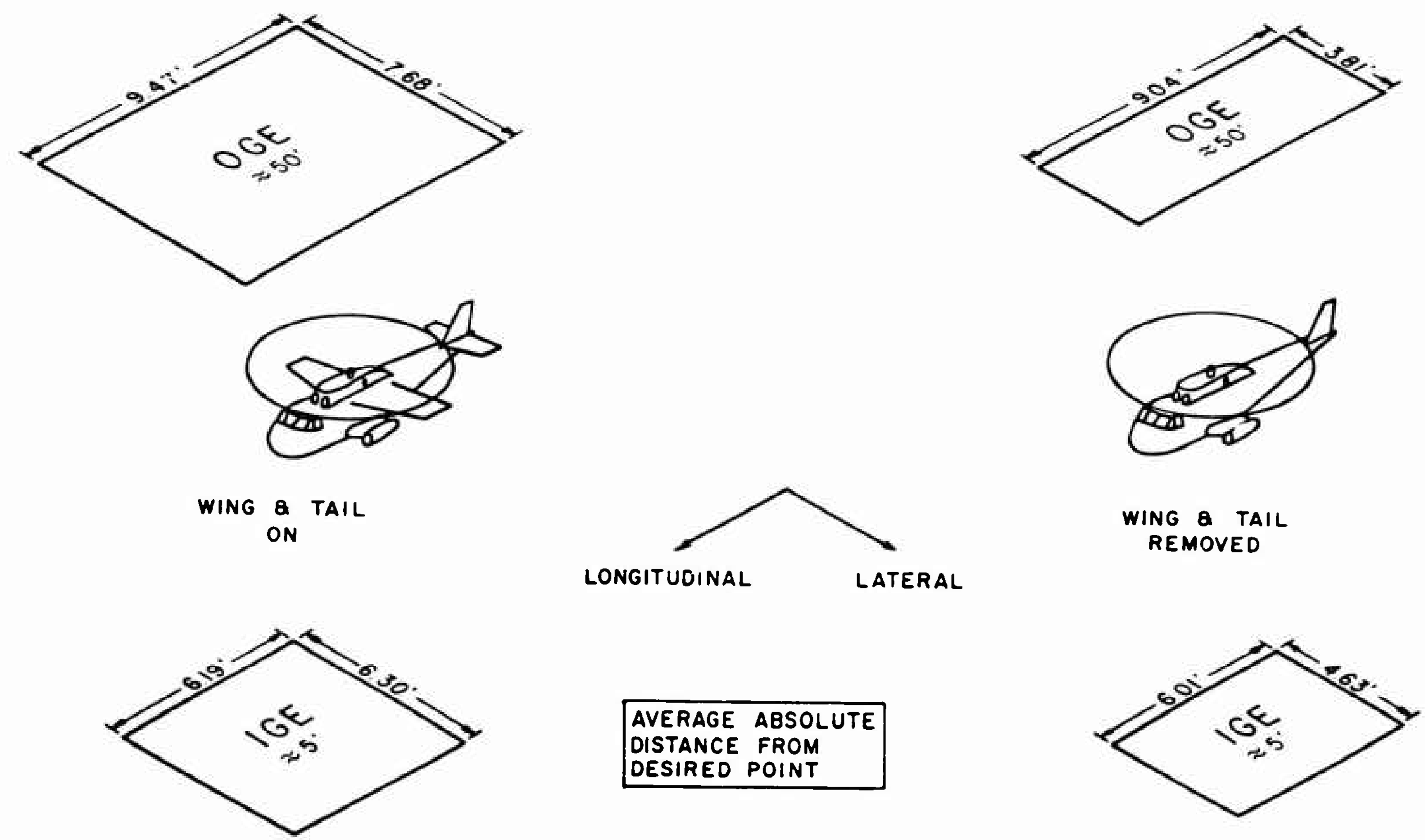


FIGURE 18. HOVER — AVERAGE ABSOLUTE HORIZONTAL ERROR

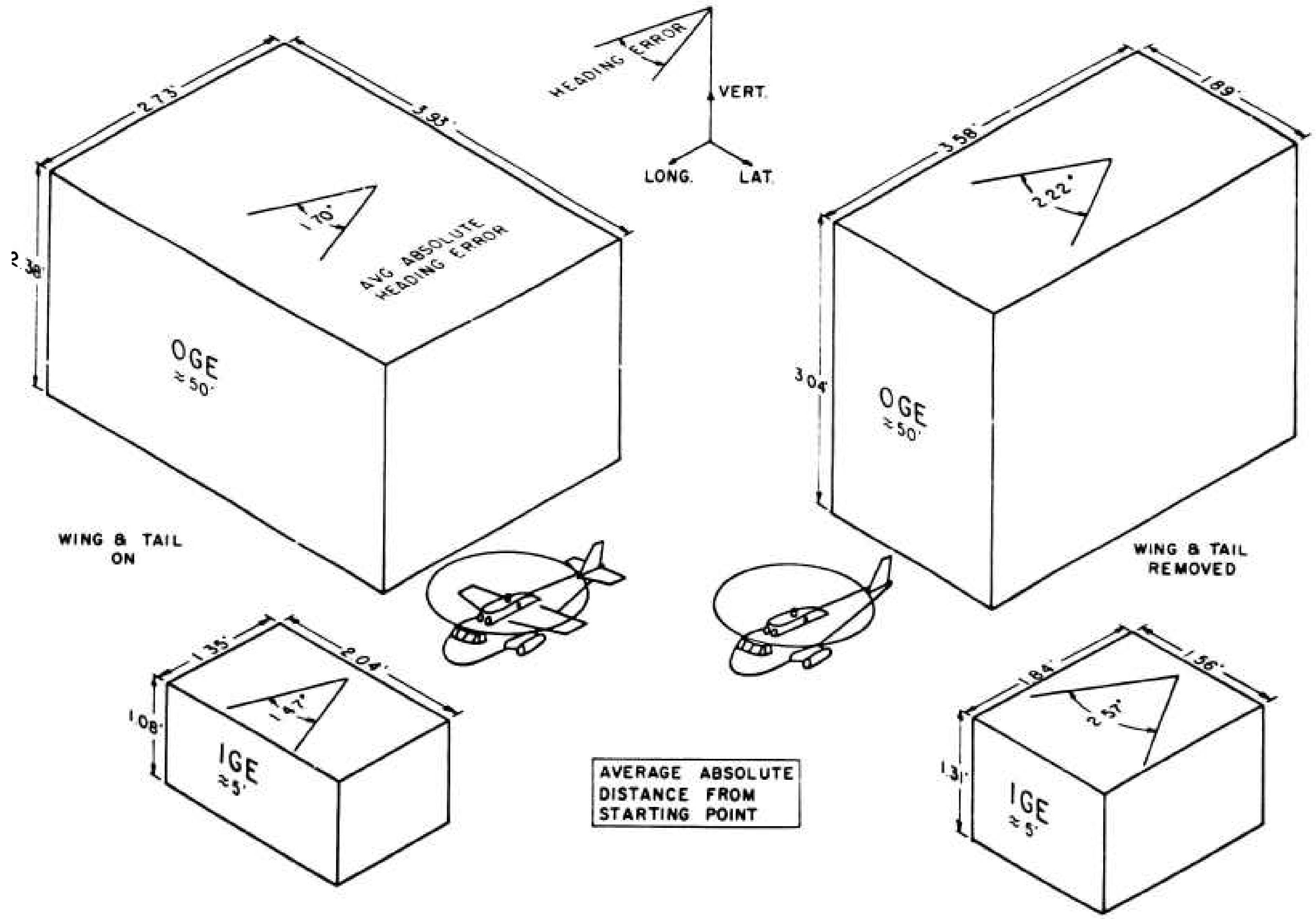


FIGURE 19. HOVER — OFFSET ERROR

TABLE IV. HOVER — ANALYSES OF VARIANCE RESULTS

PARAMETERS	Configuration A	Height B	Pilots C	A x B	A x C	B x C	A x B x C
CAMERA DATA							
Longitudinal Position							
Offset Error	N.S.	X	N.S.	N.S.	N.S.	N.S.	N.S.
Standard Deviation	X	X	X	N.S.	X	N.S.	N.S.
Lateral Position							
Offset Error	X	X	N.S.	N.S.	N.S.	N.S.	N.S.
Standard Deviation	X	X	X	X	X	N.S.	N.S.
Vertical Position							
Offset Error	N.S.	X	N.S.	N.S.	X	N.S.	X
Standard Deviation	N.S.	X	N.S.	N.S.	X	N.S.	N.S.
TAPE DATA							
Yaw - Average Integrated Error	X	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Pitch Rate Standard Deviation	N.S.	X	N.S.	N.S.	N.S.	X	N.S.
Roll Rate Standard Deviation	N.S.	X	X	N.S.	X	N.S.	N.S.
Yaw Rate Standard Deviation	N.S.	X	X	N.S.	N.S.	N.S.	N.S.
Longitudinal Cyclic							
Average Rate	X	X	X	X	X	N.S.	N.S.
Average Position	X	X	X	X	X	X	X
Steady Time	N.S.	X	X	X	N.S.	X	N.S.
Median Frequency	X	X	X	X	X	X	N.S.
Cutoff Frequency	X	X	X	X	X	X	N.S.
Lateral Cyclic							
Average Rate	X	X	X	N.S.	X	N.S.	N.S.
Average Position	X	X	X	N.S.	X	N.S.	N.S.
Steady Time	N.S.	X	X	N.S.	X	N.S.	N.S.
Median Frequency	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.
Cutoff Frequency	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.
Pedals							
Average Rate	N.S.	X	X	N.S.	X	X	N.S.
Average Position	N.S.	X	X	N.S.	X	N.S.	N.S.
Steady Time	X	X	X	N.S.	X	X	N.S.
Collective							
Average Rate	X	N.S.	N.S.	X	X	N.S.	N.S.
Average Position	X	N.S.	N.S.	N.S.	X	N.S.	N.S.
Steady Time	N.S.	X	N.S.	X	X	X	N.S.

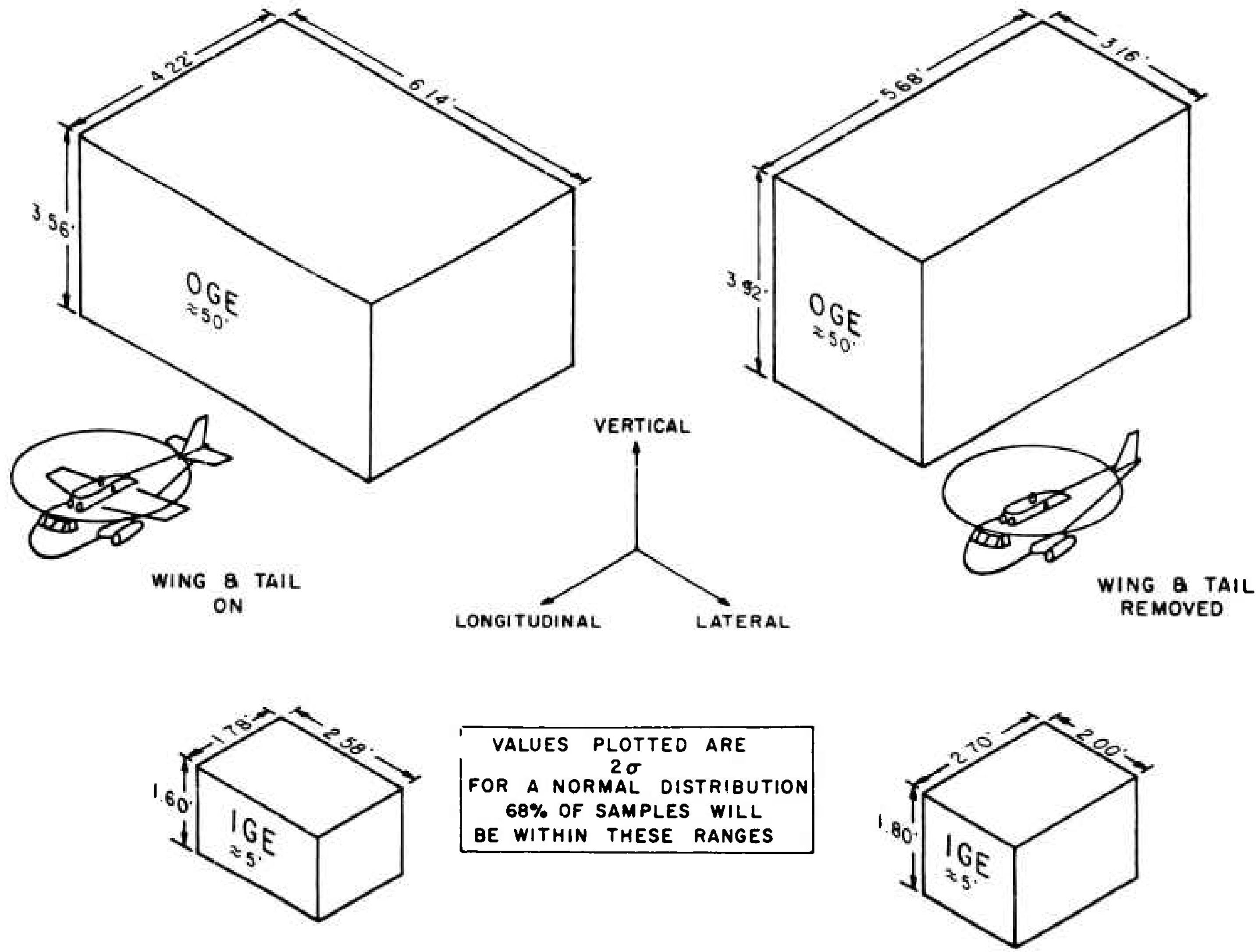


FIGURE 20. HOVER — STANDARD DEVIATIONS OF POSITION

configuration changes. The comparison between IGE and OGE consistently indicated better precision in the IGE condition, with all differences being significant.

Peak Error Data

Maximum excursions in each direction were recorded for each trial. Peak envelopes were calculated by measuring the distance between opposite peaks. The averages of these envelopes are shown in Figure 21. Once again it is possible to see improvement in longitudinal performance and the degradation in lateral performance produced by wing and tail. The clear differences between IGE and OGE are again apparent.

Figure 22 shows the maximum envelopes which were measured for all pilots and all trials under each condition. Effects of IGE vs. OGE and configuration are seen to be similar to previous figures.

Work-Load Measures

Several types of data believed to be indicative of pilot work load are included in this section. Among these are aircraft attitude rate measures to indicate aircraft activity, control position and rate measures, and power spectral density analyses of control position to evaluate control amplitude, rate, and frequency.

Attitude Rate

Figure 23 makes use of isometric plotting techniques to show the attitude rate data graphically in the planes in which motions occur. The data plotted are the standard deviations of roll, pitch and yaw rates and are indicative of the spreads of rate about the mean rate (which is approximately 0). For a normal distribution the attitude rate would be within the values shown 68% of the time. There is a consistent and statistically significant reduction of rates in all axes for the OGE conditions as compared with the IGE conditions. Differences due to configuration are not significant.

Control Positions

Figures 24 and 25 show the mean, standard deviation, and maximum extents of control position used by the three pilots over five trials. For the IGE hover conditions, Figure 24, the major differences are seen in the longitudinal and lateral cyclic stick positions. For the wing-and-tail-on configuration, the mean

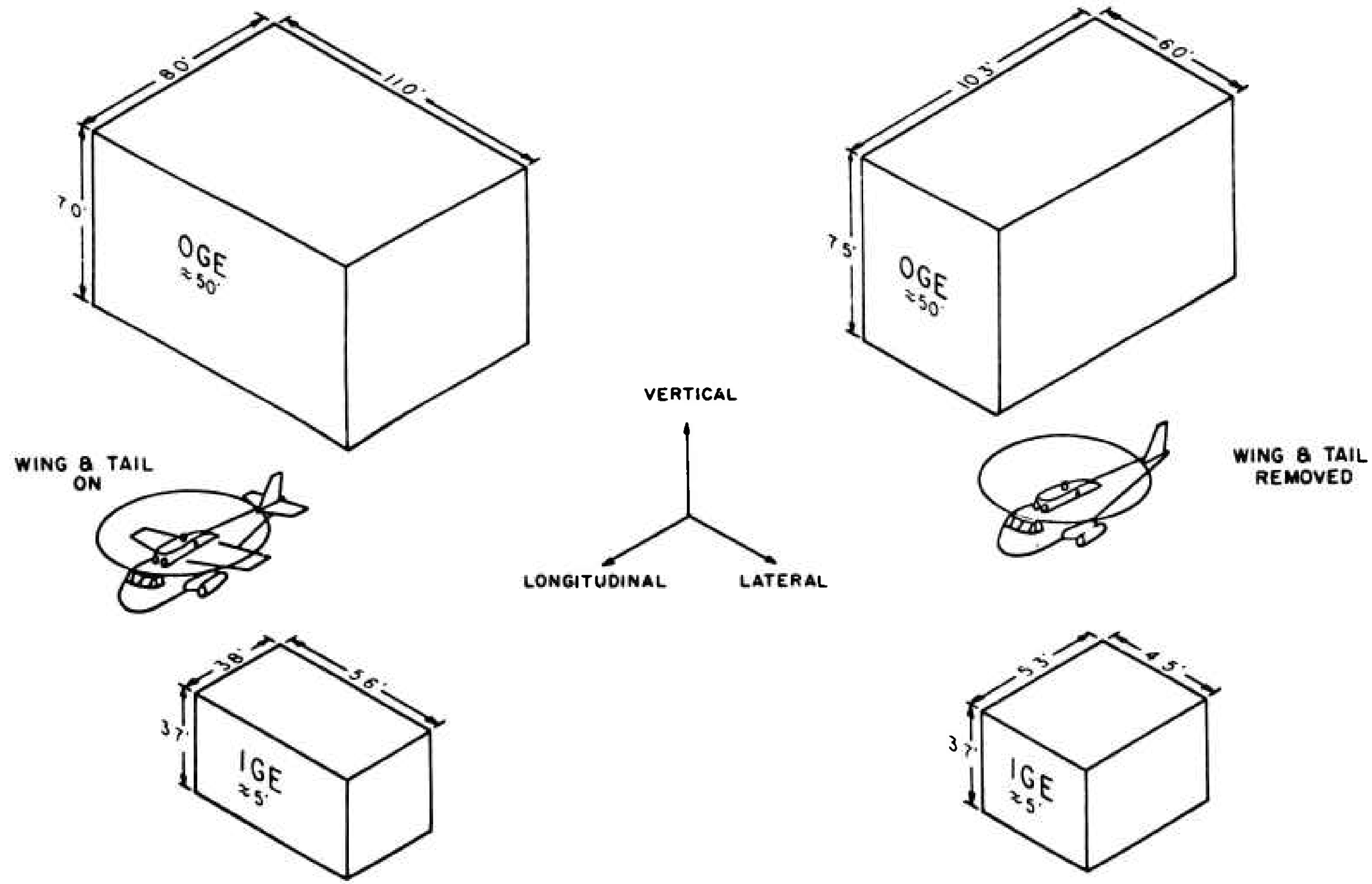


FIGURE 21. HOVER — AVERAGE PEAK ERROR

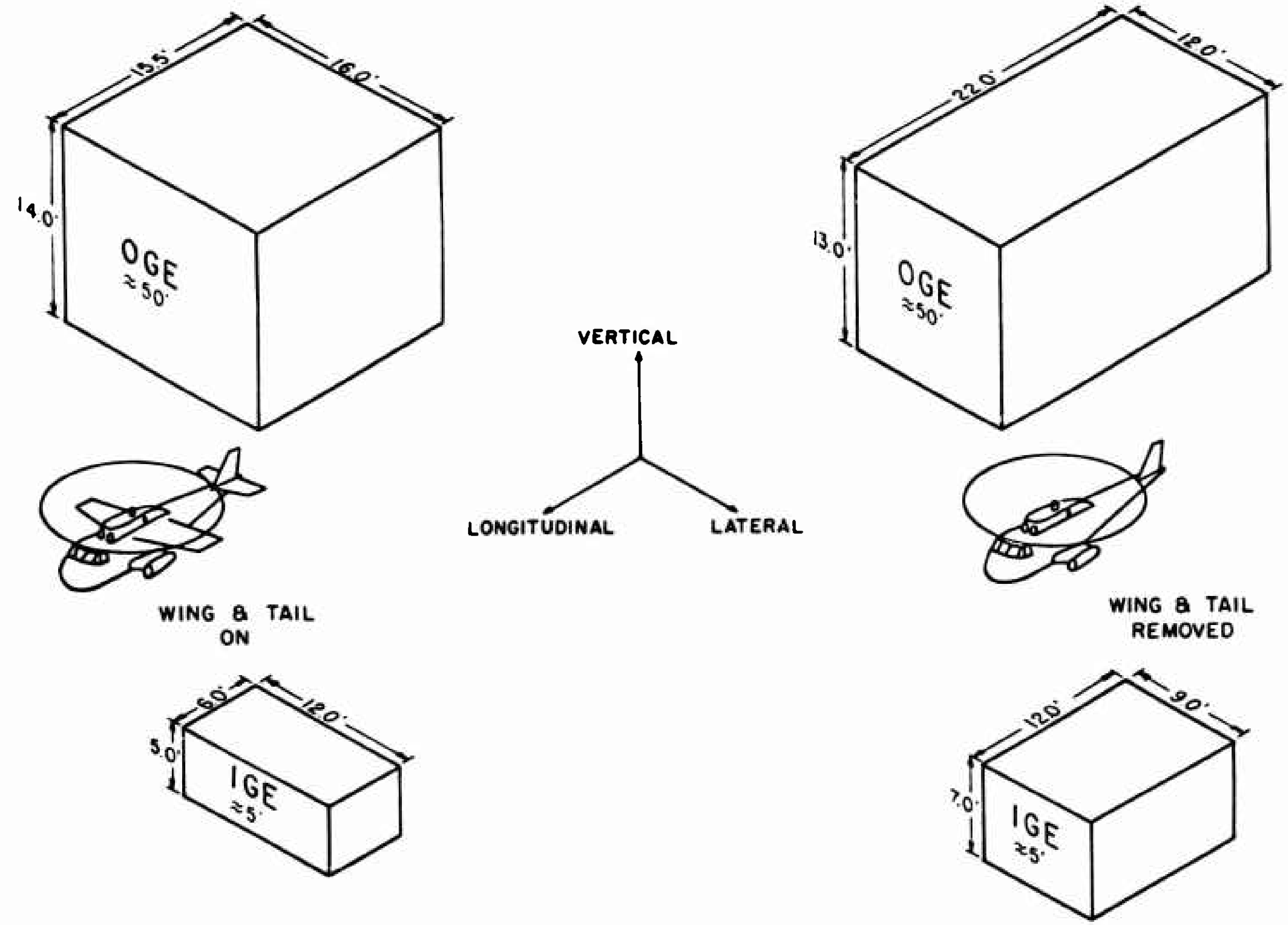


FIGURE 22. HOVER — MAXIMUM PEAK ERROR

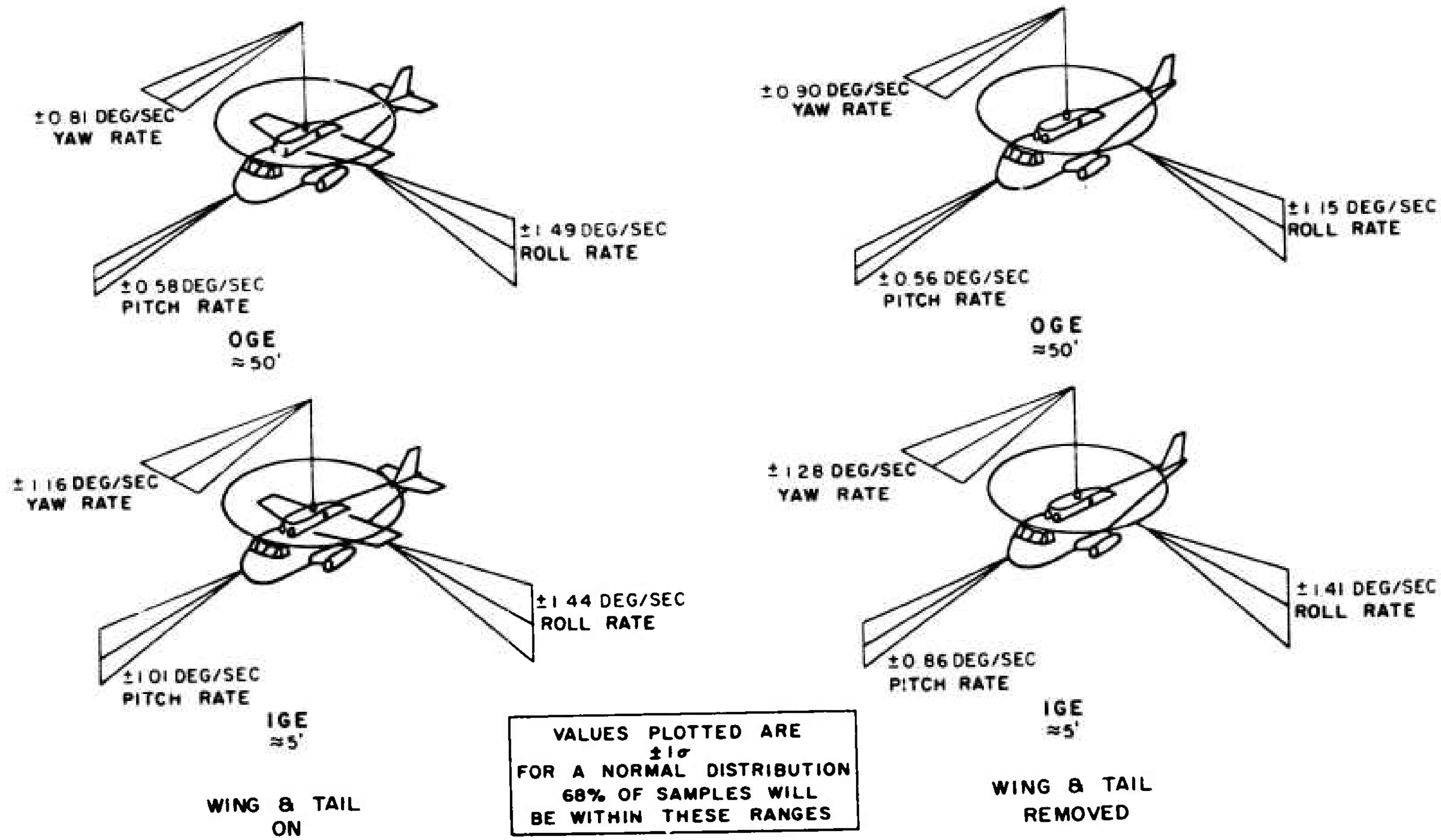


FIGURE 23. HOVER — ATTITUDE RATES

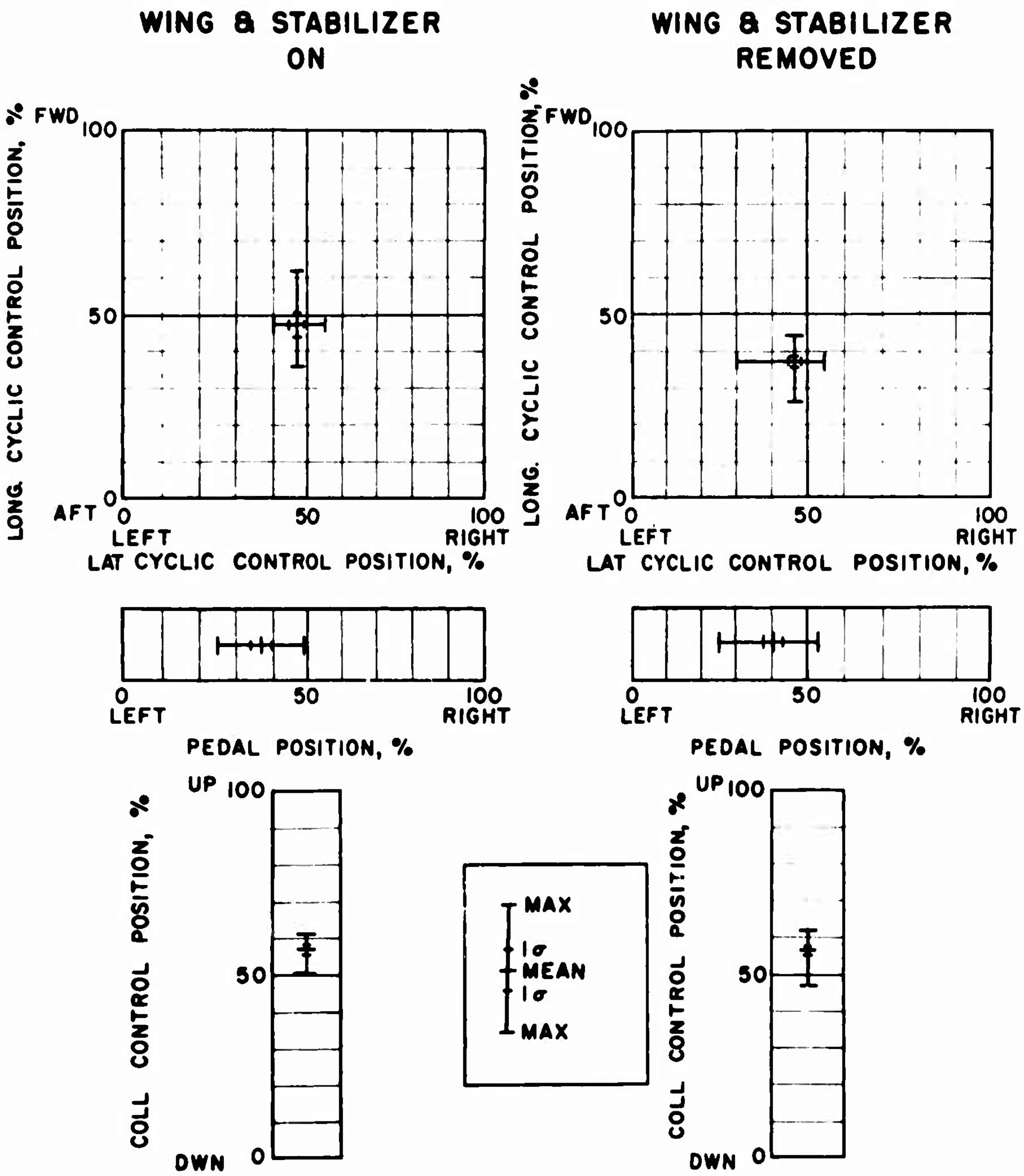


FIGURE 24. HOVER IGE — CONTROL POSITIONS

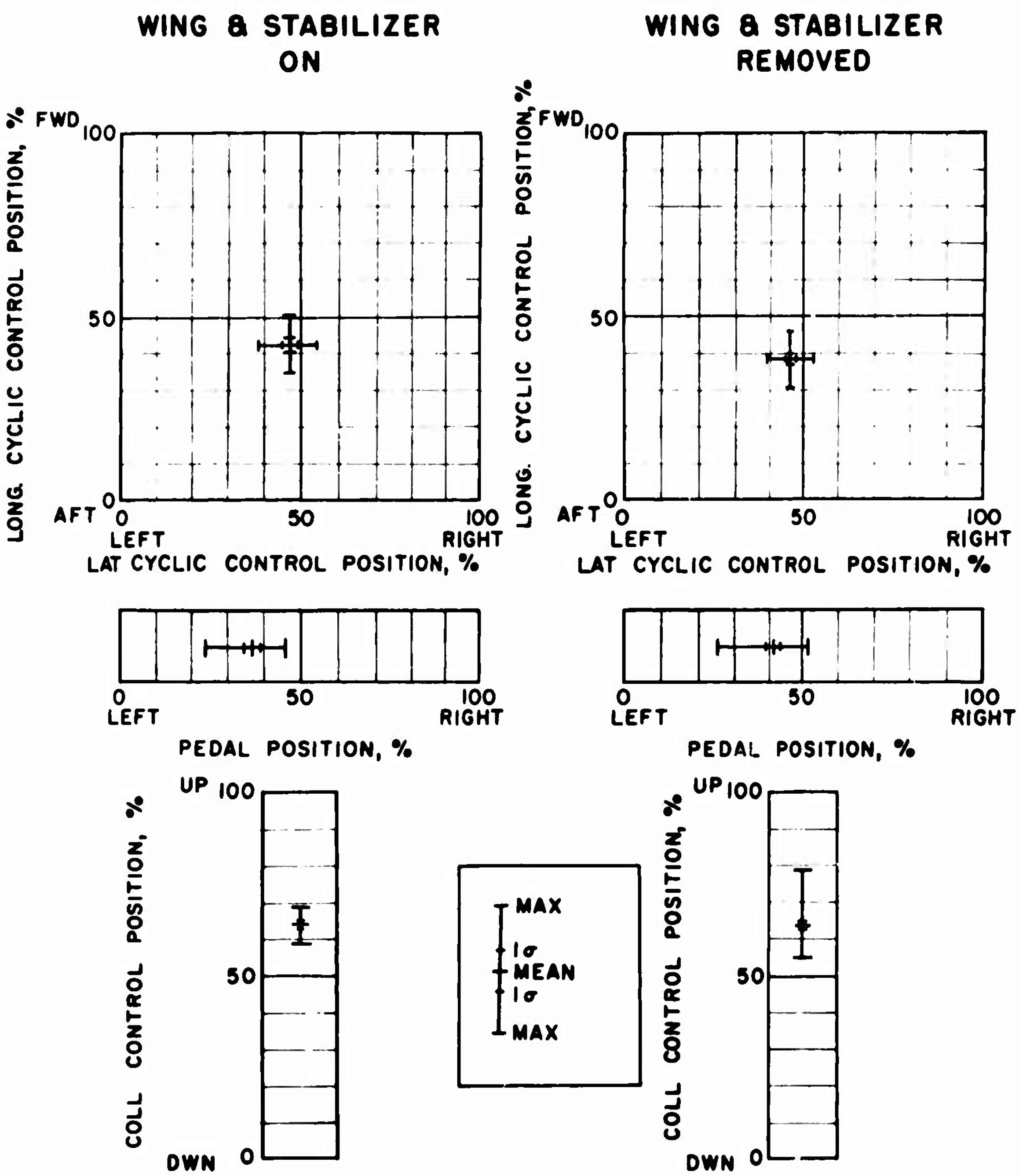


FIGURE 25. HOVER OGE — CONTROL POSITIONS

longitudinal stick is approximately 10% forward of its mean position with the wing and tail removed. This is the shift in stick trim required to offset the nose-up pitching moment resulting from the rotor downwash on the horizontal stabilizer. In addition, greater extents of longitudinal control motion were used with wing and tail on to control the randomly occurring pitching motions. This also resulted in greater longitudinal and lateral cyclic standard deviation intervals for the compound configuration. Figure 25 shows that there is less difference between configuration related control motion characteristics when hovering OGE. There is, however, a 5% forward shift in longitudinal trim and slightly greater values for the longitudinal and lateral cyclic control standard deviation measures for the compound configuration.

Control Activity

Figures 26 and 27 show four measures of control activity which were considered to be indicative of pilot work load. The first of these, average control rate, clearly shows the effects of configuration and IGE vs. OGE for each control. All differences are statistically significant with two exceptions: pedal rates with configuration and collective rates with height. The higher rates found in ground effect and in the wing-and-tail on configuration reflect the greater difficulty in controlling the attitude of the vehicle.

The measures of control position indicate the average amplitude of control inputs. Longitudinal and lateral control amplitudes show the same effects as the control rate measures; that is, in ground effect and wing and tail on, the average magnitudes of inputs are larger than OGE and wing and tail off.

Two additional measures of control activity are shown in Figure 27. The first, steady time, reflects the percentage of time the control is held still or moved at a rate below .5% total travel per second. The larger the value, the less activity which occurred. Configuration produced a significant difference only in pedal steady time, with the wing-and-tail-on condition having less activity. Hover altitude produced significant effects on control steady time, with a considerable increase in steady time OGE as compared to IGE conditions.

Number of mean crosses is the second measure shown in Figure 27. Using this measure, longitudinal and lateral sticks show similar patterns of increase from wing-and-tail-on to wing-and-tail-off and from IGE to OGE. Collective shows the opposite effect for both configuration and height.

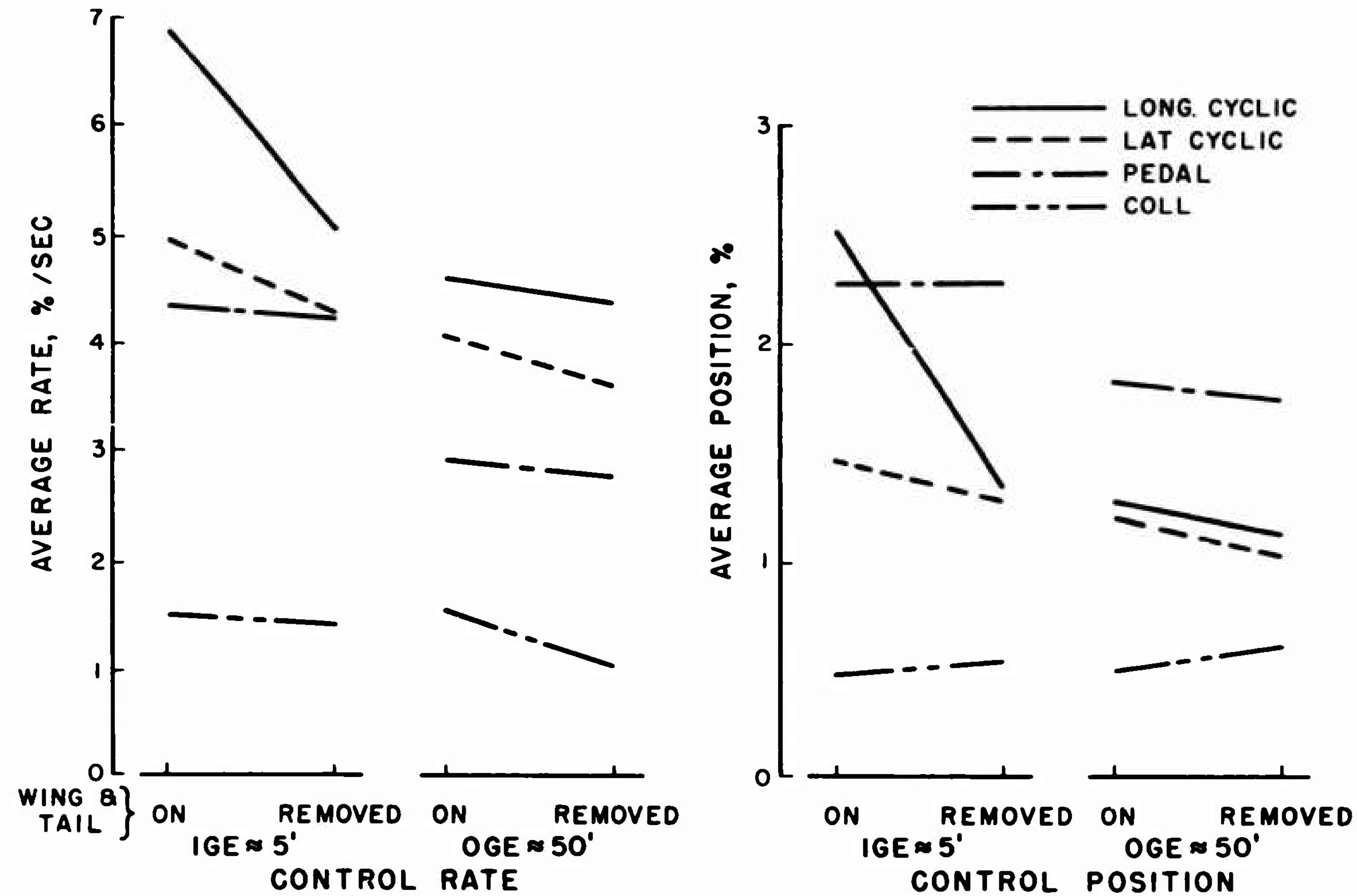


FIGURE 26. HOVER — CONTROL RATE AND AMPLITUDE

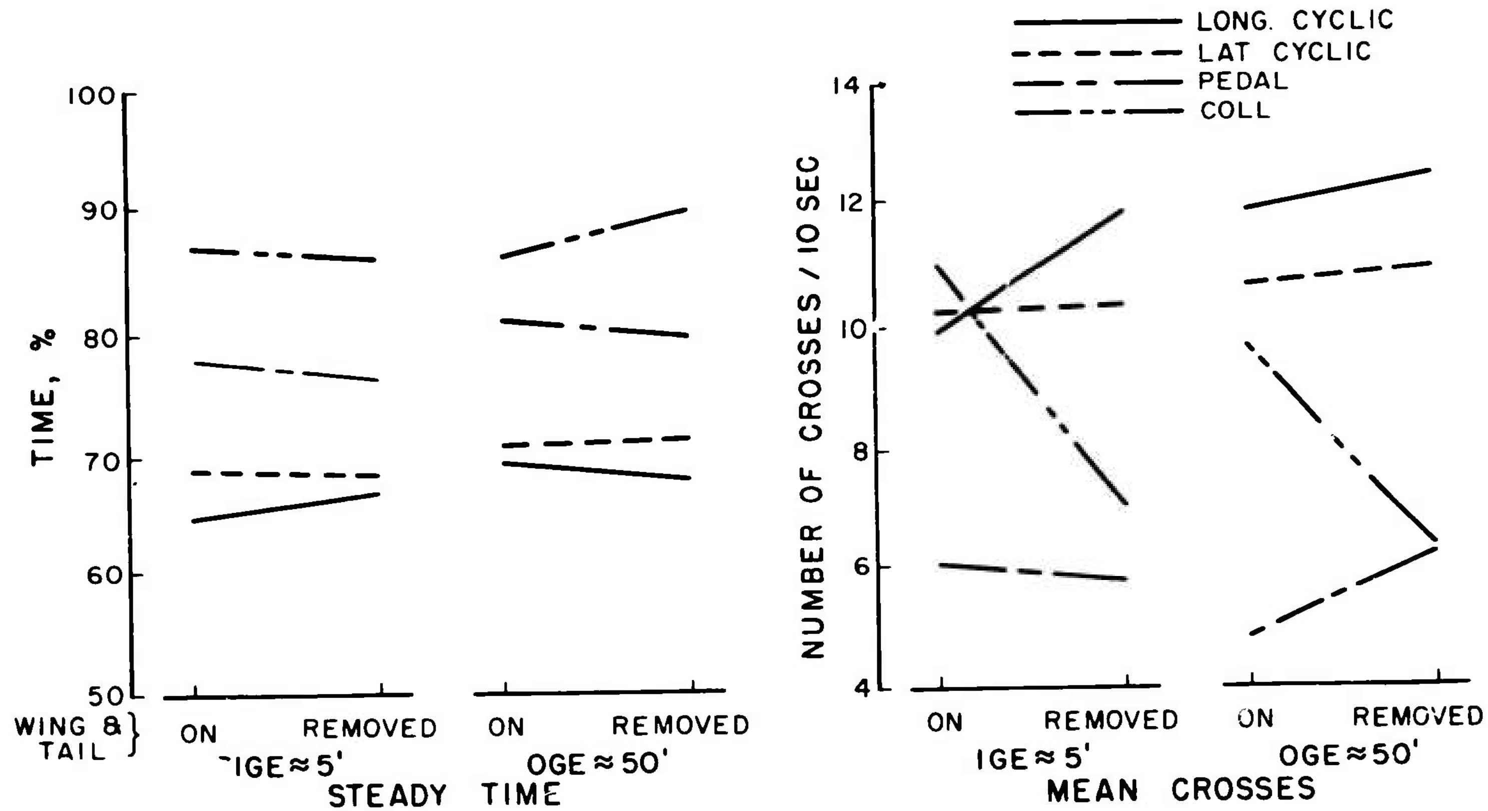


FIGURE 27. HOVER — CONTROL STEADY TIME AND MEAN CROSSES

Power Spectral Density (PSD)

To evaluate another technique for work-load measurement, power spectral densities were calculated for each of the controls for all trials. The techniques for calculation of these data are described in Appendix II. It is important to keep in mind that the power spectral densities are based on normalized auto-correlation functions. Information on the overall magnitude of the control input signal is lost in the normalization process; thus the power spectral density represents only the relative power at each frequency. The amplitude information was presented separately in a previous section.

Mathematical purity requires that the signal being analyzed with this technique be a "stationary ergodic process." It was considered unlikely that human pilot output would meet this requirement. However, the major interest here was not to precisely pinpoint the pilot's output frequency, but rather to find measurement techniques which would be sensitive to difference in vehicle handling qualities. With these qualifications in mind it was decided to compute several numerical summary scores from the PSD data.

The five measures computed were the mean, median, mode, standard deviation and cutoff frequency. Details of the computation techniques employed are described in Appendix II. Briefly, the mean frequency is the arithmetic average of the frequencies; the mode is the frequency of greatest power; the median is the frequency where 50% is lower; and the cutoff is the frequency where 95% of the power is lower and 5% is higher. Figure 28 shows the effects of configuration and height of hover on these measures of frequency for longitudinal and lateral cyclic pitch control. For each of the measures of longitudinal control there is a clear indication of increased frequency with the wing and tail off. This is particularly evident for the IGE condition where the wing-and-tail-off frequencies are about .2 cps higher. Table IV indicates that the median and cutoff frequencies differ significantly with configuration, height and pilots.

Lateral, on the other hand, does not differ with configuration or height. This is evident in the lateral control portion of Figure 28 and is reinforced by the analyses of variance in Table IV, which shows that the lateral control median and cutoff frequencies differ significantly only with pilots.

Much can be gained from direct analysis of the frequency plots, Figures 29 through 34, which show the in ground effect hover

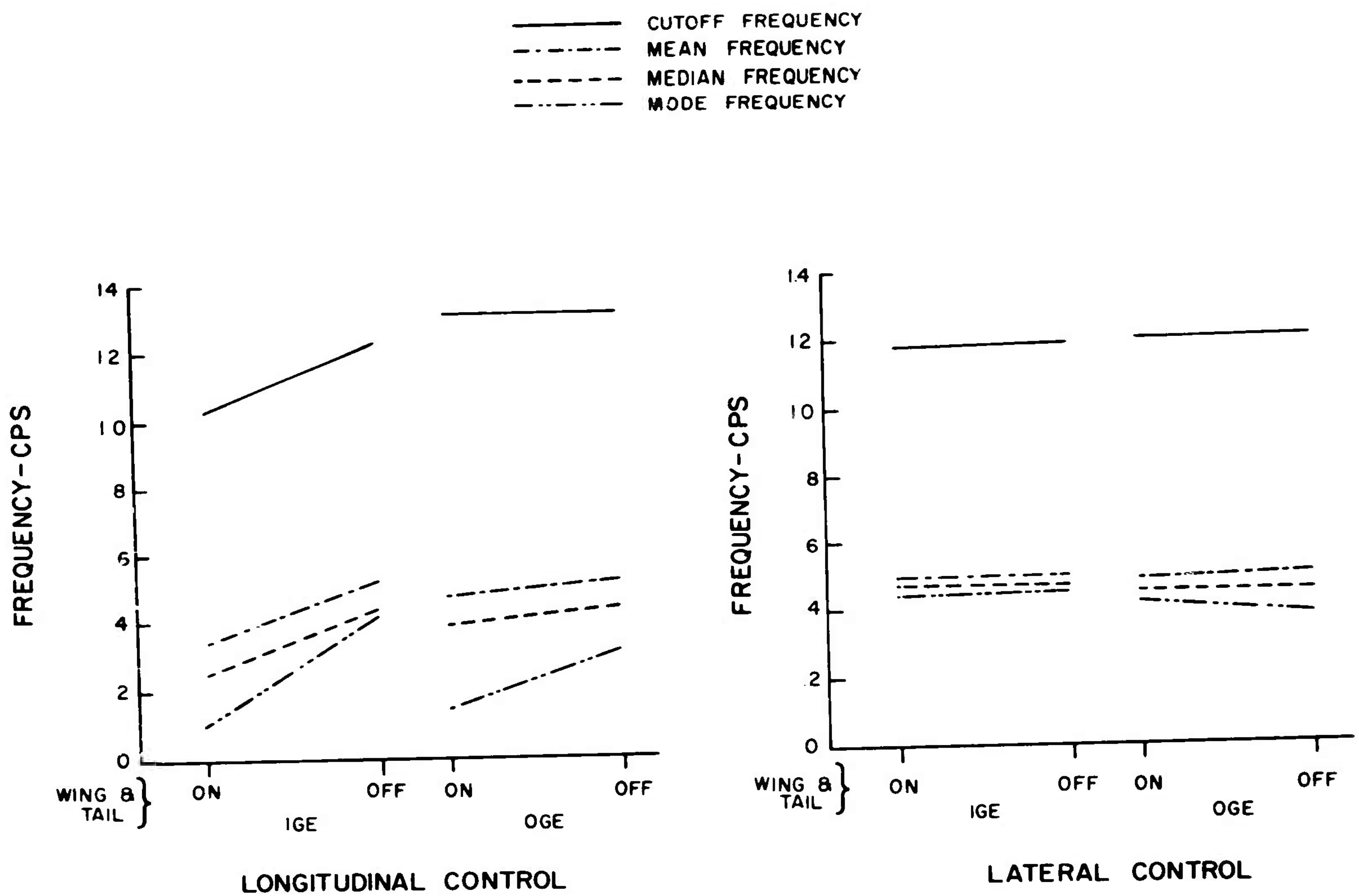


FIGURE 28. HOVER — POWER SPECTRAL DENSITY MEASURES

FLIGHT 3 PILOT 1
IN GROUND EFFECT HOVER
WINGS AND STABILIZER ON
LONGITUDINAL STICK

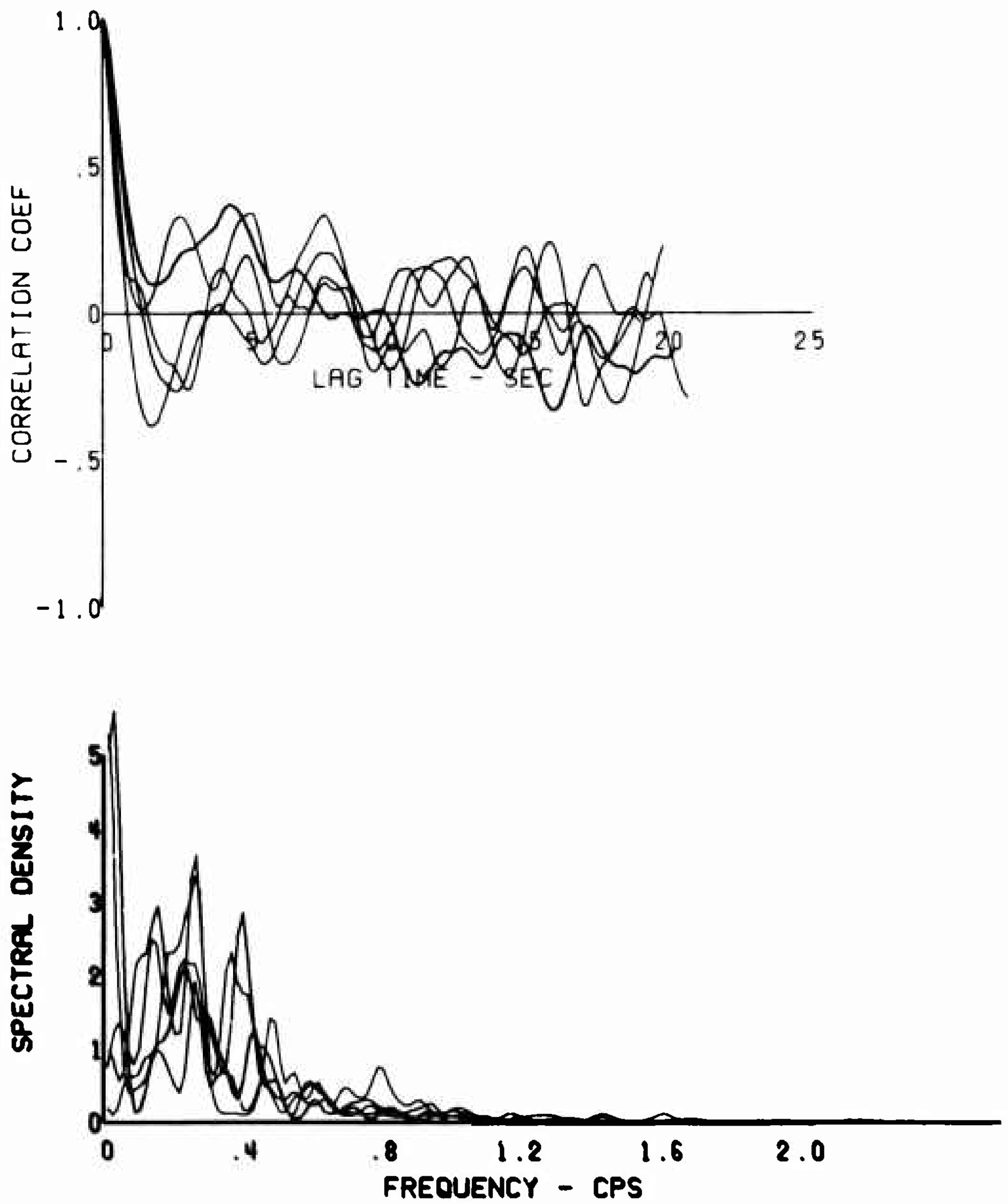


FIGURE 29. PSD (POWER SPECTRAL DENSITY) - PILOT 1 - WINGS AND STABILIZER ON

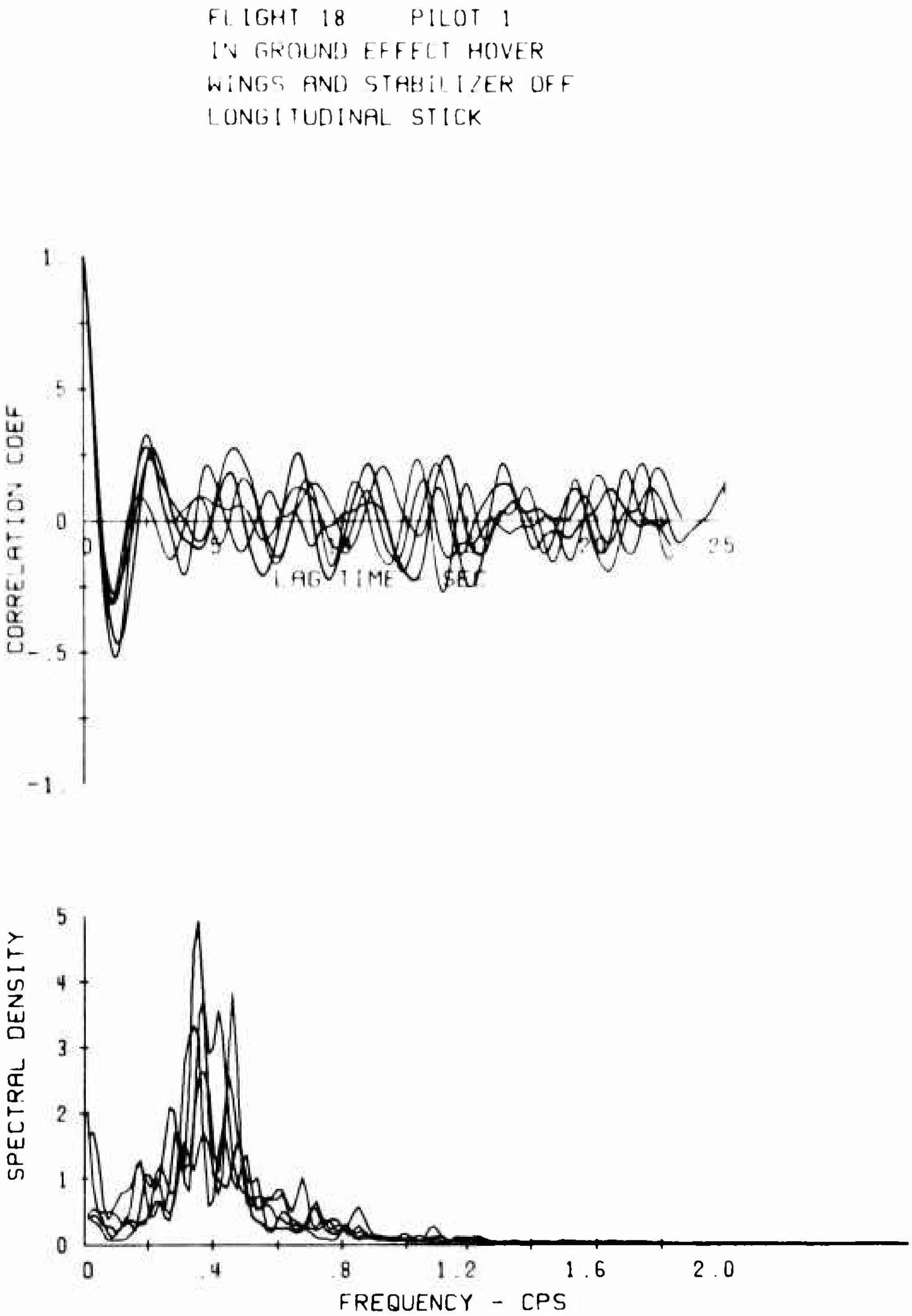


FIGURE 30. PSD — PILOT 1 — WINGS AND STABILIZER OFF

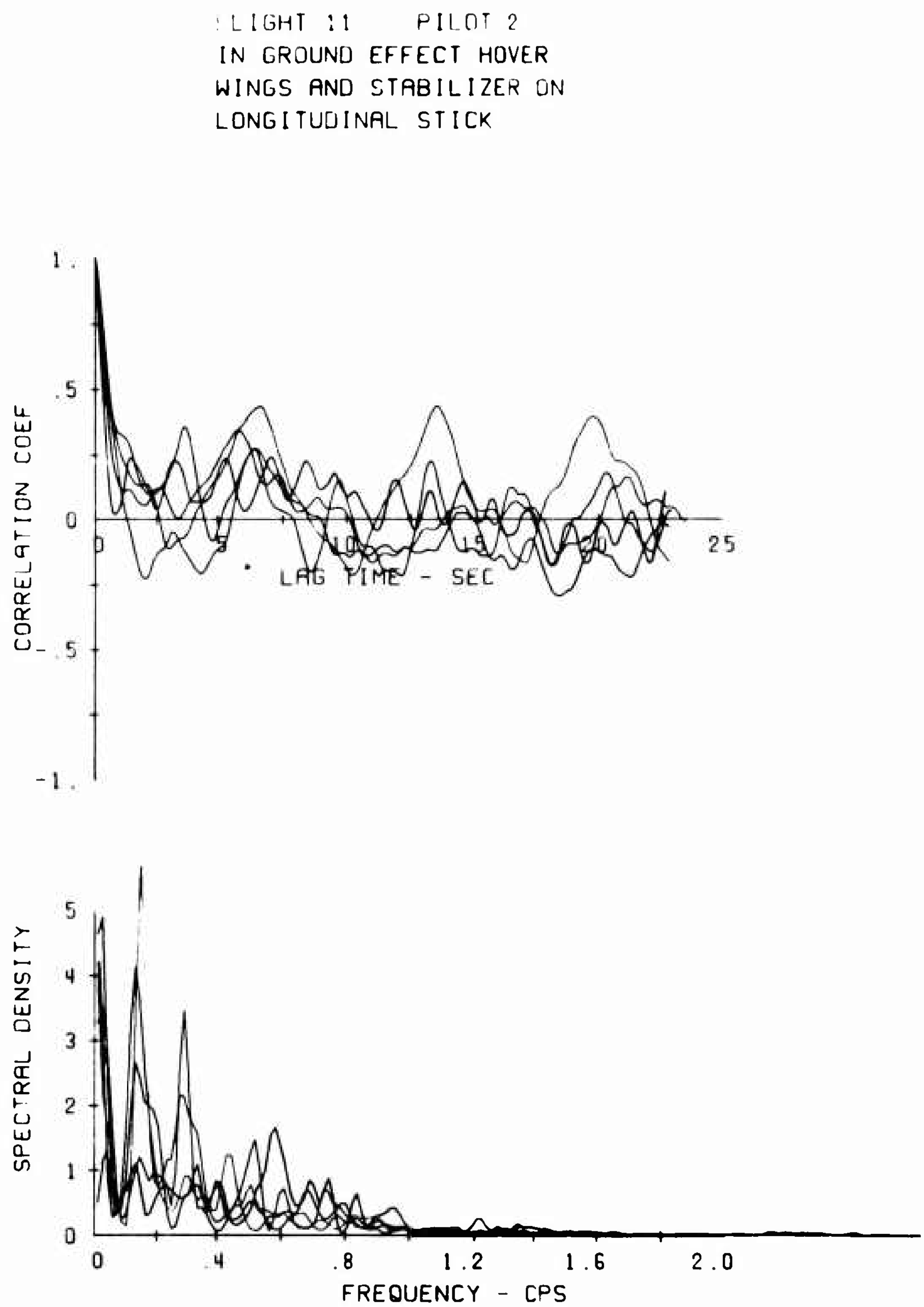
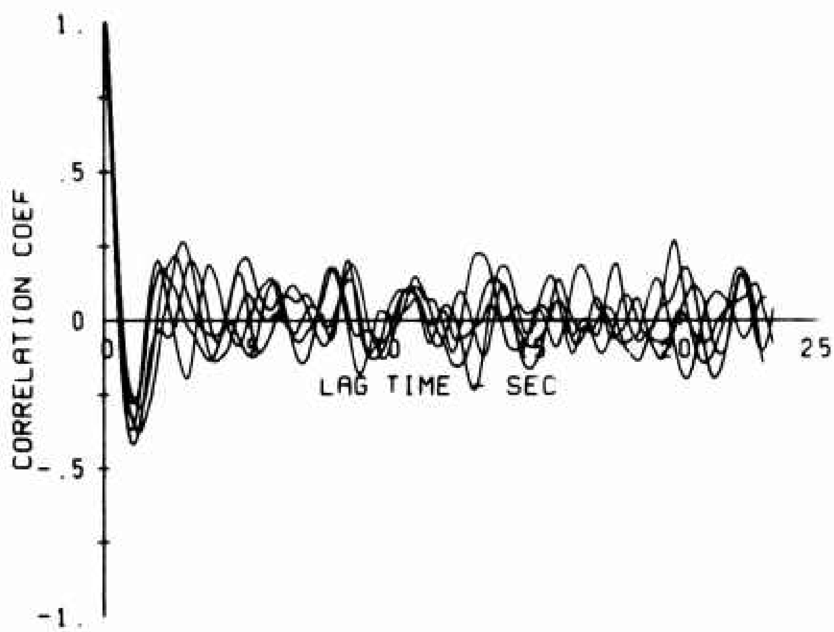


FIGURE 31. PSD — PILOT 2 — WINGS AND STABILIZER ON

FLIGHT 17 PILOT 2
IN GROUND EFFECT HOVER
WINGS AND STABILIZER OFF
LONGITUDINAL STICK



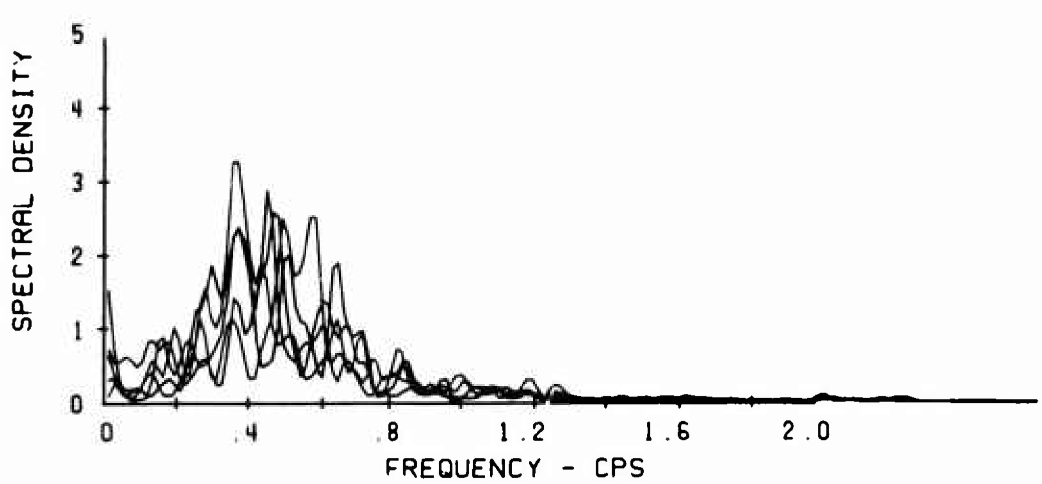


FIGURE 32. PSD — PILOT 2 — WINGS AND STABILIZER OFF

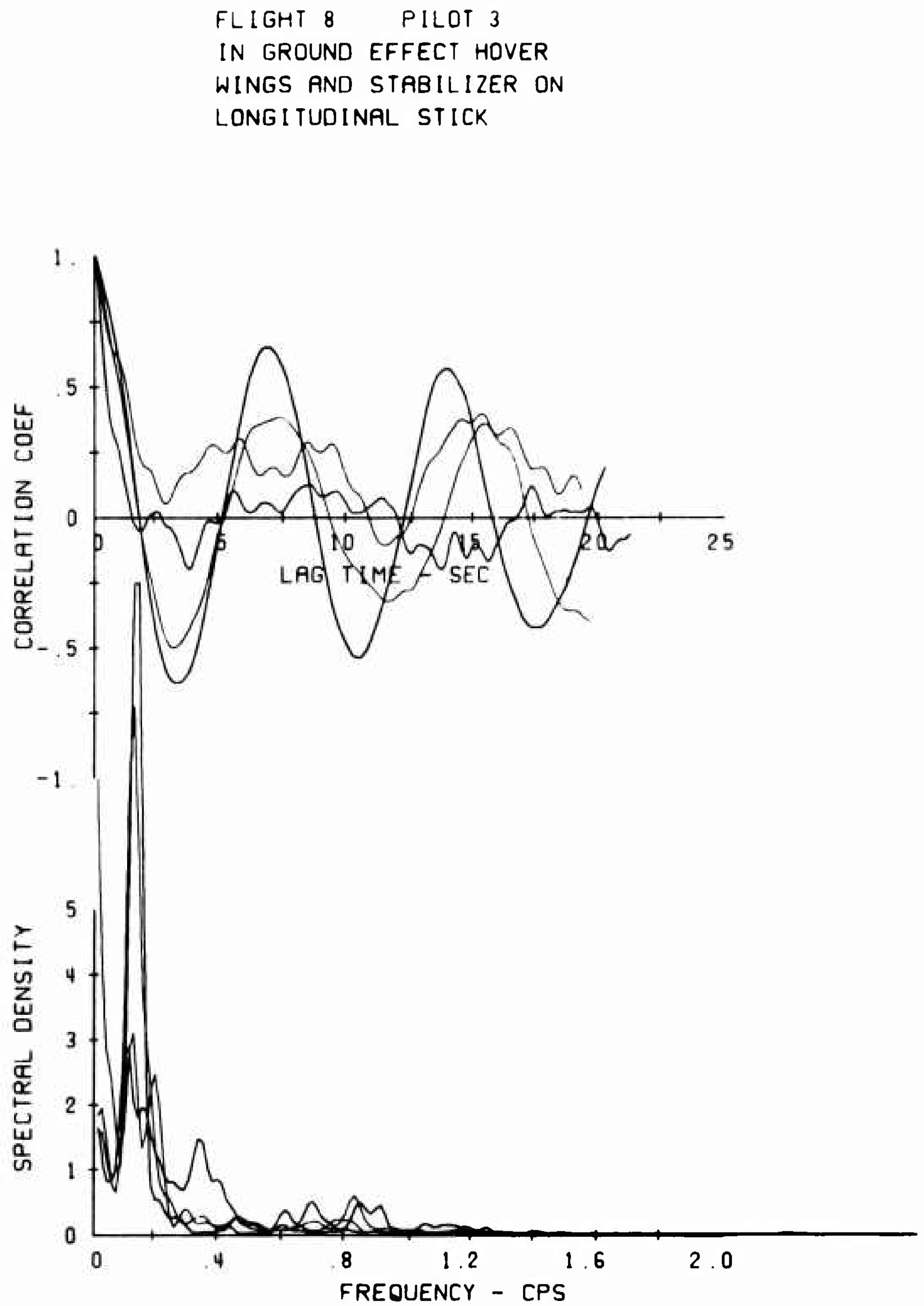


FIGURE 33. PSD — PILOT 3 — WINGS AND STABILIZER ON

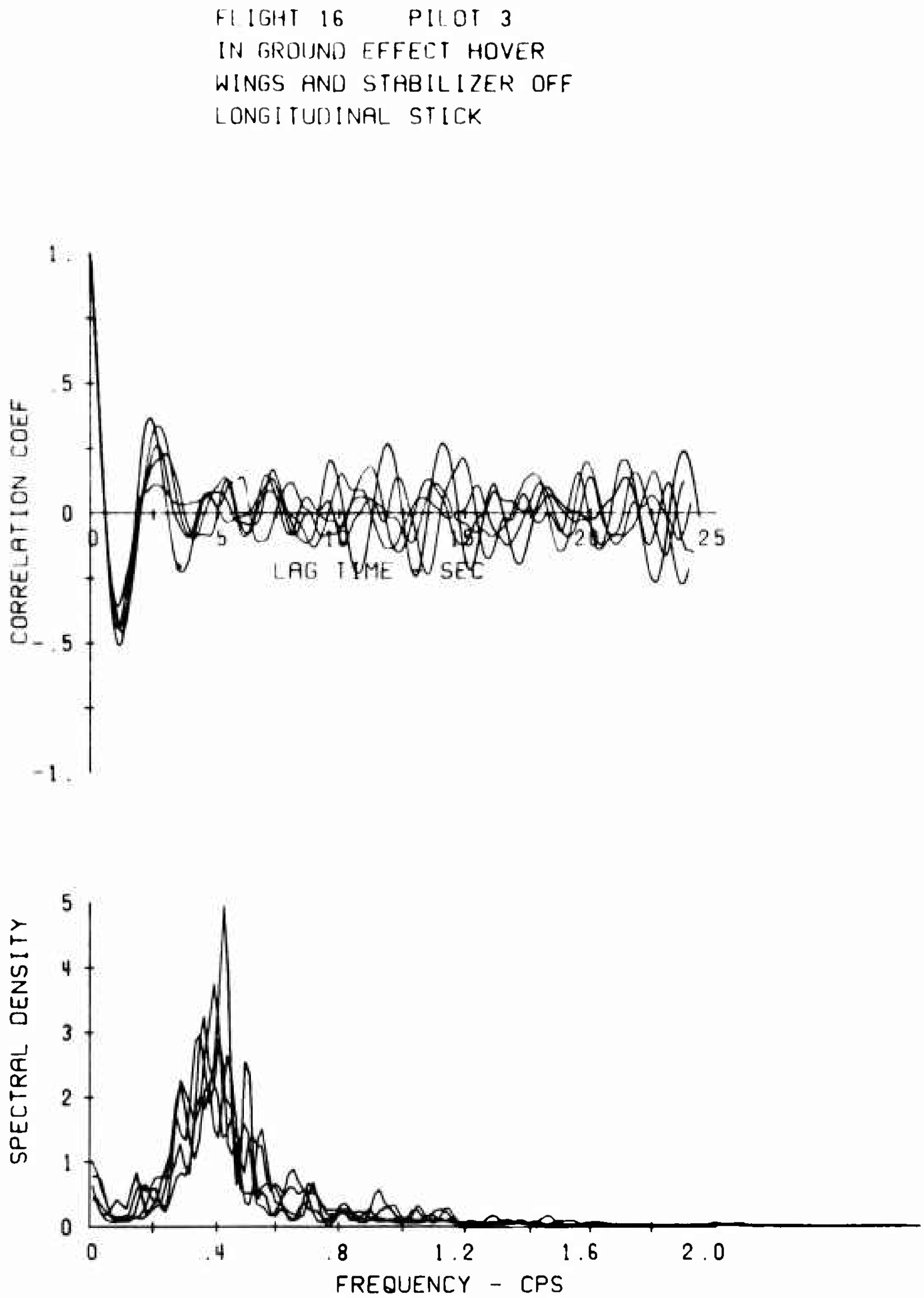


FIGURE 34. PSD — PILOT 3 — WINGS AND STABILIZER OFF

longitudinal stick PSD for both configurations for each pilot. These figures have the superimposed traces of the auto-correlation functions and PSD for the five trials run at each condition. It should be noted that the differences in frequency, which were calculated numerically for Figure 28, are evident in these plots. Considerable variability from trial to trial indicates that man does not generate a stationary ergodic control output. There is, however, considerable similarity among the five traces in most cases. The band defined by the highest and lowest trace might be thought of as an envelope in which the true value probably lies. The width of the band does indicate that one should be cautious about the interpretation of a signal trace when the duration of the single from which it was computed is not known. The differences between each pilot's input frequency content for the two configurations are striking. For the wing-and-tail-off configuration the input signals are quite predictable, with a fairly low intertrial variability and a peak between .4 and .5 cps. With the wing and tail on, however, there appears to be more variability, a wider spread of frequency content and more power at the very low frequency end of the scale.

Individual differences among the three pilots are also evident. In fact, in much of the PSD data these individual differences are more pronounced than differences due to configuration. A comparison of the two in ground effect hover plots by Pilot 2 with those of Pilots 1 and 3 shows that Pilot 2 puts in considerably more power above .6 cps than do the other two pilots.

Pilot Opinion Data

Figure 35 shows the pilot opinion data collected in the hover phase. Three types of data were collected: (1) performance rating in five steps from good to poor, (2) work-load rating in five steps from easy to hard and (3) Cooper-Harper pilot rating of aircraft. The first two ratings were taken after each trial, and the Cooper-Harper rating was assigned to the aircraft at the end of each flight phase.

Each symbol on the upper two scales in Figure 35 is the mean of five trials for each pilot. Pilots 1 and 2 rated their performance worse with wing and tail off, while Pilot 3 felt that his performance improved. Pilots 2 and 3 rated OGE performance better than IGE performance; however, Pilot 1 rated OGE and IGE performance equal with wing and tail on and OGE poorer with wing and tail off.

When the pilots rated their work load, 1 and 3 felt the wing-and-tail-on configuration was slightly harder, while Pilot 2 rated this configuration slightly easier in ground effect. Out of ground effect, Pilots 1 and 2

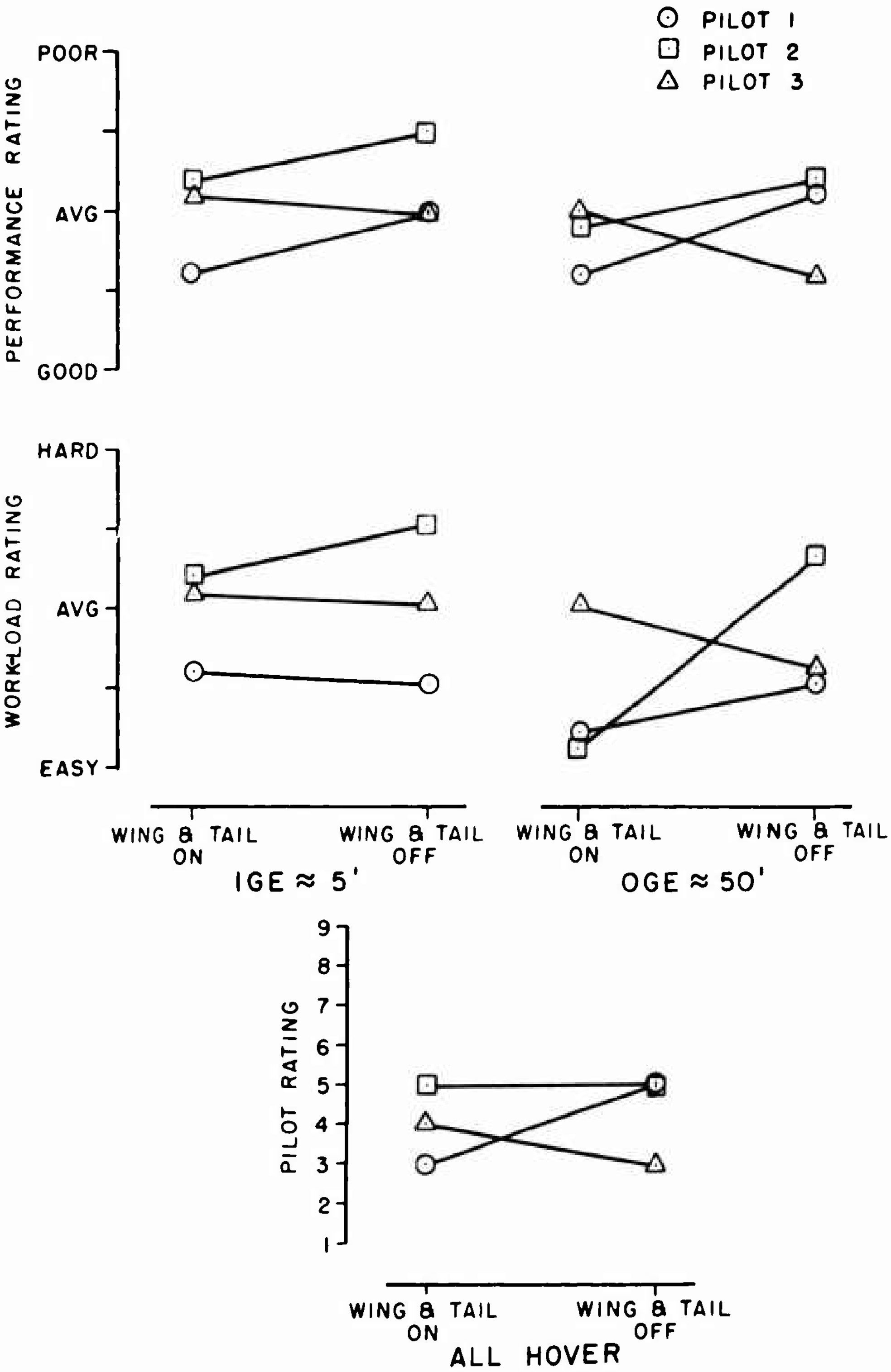


FIGURE 35. HOVER — PILOT OPINION DATA

rated the wing-and-tail-on configuration easier and Pilot 3 rated it more difficult.

Except for one equal point, all mean ratings of work load for OGE were easier than the corresponding IGE points.

The more conventional Cooper-Harper rating given by each pilot for the aircraft at the end of each hover and hover turn flight indicates that there is disagreement among the pilots regarding the effect of wings and horizontal stabilizer. Pilot 1 rates the wing-and-tail-on configuration A-3 and rates the wing-and-tail-off configuration A-5. Pilot 2 rates both configurations A-5, and Pilot 3 rates the wing-and-tail-on configuration A-4 and the wing-and-tail-off configuration A-3, one point better.

Evaluation

In order to fairly assess the effects of wing and tail on handling qualities, it is necessary to view the entire picture of precision, work load, and opinion.

For the precision data, the wing-and-tail-on configuration appeared better longitudinally while the wing-and-tail-off configuration seemed better laterally. The superiority of the wing-and-tail-on configuration was unexpected because of pilots' comments prior to the program indicating pitch control difficulties at low speed due to the rotor downwash striking the horizontal stabilizer. An analysis of the situation led to the discovery that this pitching motion was contributing in a positive way to longitudinal hover precision. This speed stability effect is due to the fact that when the aircraft moves forward the download on the horizontal stabilizer increases as the downwash flows to the rear, resulting in a nose-up pitching moment which tends to stop the forward motion.

The reasons for lateral improvement with the wing and tail off are more obscure. The suggestion has been made that the wing may be tending to tuck due to lateral velocity in sideward flight resulting in reduction of lateral speed stability. A more plausible explanation would combine this effect with heavier downwash impingement on the wing in the direction of lateral motion, causing an additional roll into the direction of motion.

It is quite clear from the control motion measures that work load is higher with wing and tail on. This was particularly true for longitudinal cyclic where larger and faster control inputs were required. The frequency analyses also reflected configuration differences.

Longitudinally the median and cutoff frequencies were higher for the wing-and-tail-off configuration. Thus the longitudinal control motion characteristics, with wing and tail on, indicated large inputs, at a higher average velocity, and at a lower frequency with random components. Conversely, the control characteristics for the wing-and-tail-off configuration showed smaller inputs, lower average rates, and higher, more predictable frequencies.

The effect of configuration on pilot opinion is inconsistent. The presentation of the individual pilot's opinions is perhaps unfair because the other data are averaged among the three pilots, and consequently disagreements would not be seen. Unfortunately, taking average ratings of pilots is a statistically questionable procedure because the rating scales cannot be assumed to have equal intervals between steps. Generally, the other measures do differ among pilots (control motions in particular), but with these data the assumption of equal intervals between numbers is not in question; hence the arithmetic means can be legitimately calculated.

To gain some appreciation for the interrelationships among the various measures, correlations were calculated for the longitudinal and lateral hover measures. Included are the camera data, the on-board measures, the pilot opinion data and the power and cross-spectral density measures.

The correlation coefficient is a measure of the degree to which two variables covary. The coefficients range from +1 (perfect positive correlation) through 0 (no relationship) to -1 (perfect negative correlation.) To use the matrix, select the two measures of interest, note the number corresponding to each and enter the matrix with one number along the top and the other along the left edge. Keep in mind that the camera data were error measures; thus higher scores represent worse performance. The two opinion measures were scaled such that higher values represent poorer ratings.

For these particular data, the correlation coefficients must exceed ±.56 in order to be significant at the .05 level.

The measures of longitudinal error, Table V, columns 1 and 2, correlate highly with each other but not significantly with opinion or measures of stick amplitude or rate. They did, however, correlate with the measures of the number of times the stick crossed its mean position and the measures of power and cross spectral density. These correlations were positive, indicating that higher frequencies occurred with higher errors.

The measures of longitudinal stick rate and position (5 and 6) correlated at .85 with each other, indicating that the higher rates occurred with

TABLE V. HOVER - LONGITUDINAL CORRELATION MATRIX

Group	Measure		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Camera	Longitudinal Position Standard Deviation	1	1																				
Camera	Longitudinal Position Offset	2	.93	1																			
On-Board Measures	Pitch Rate Standard Deviation	3	-.51	-.52	1																		
On-Board Measures	Pitch Rate IAE	4	-.20	-.34	.87	1																	
On-Board Measures	Longitudinal Stick Average Rate	5	-.41	-.35	.57	.25	1																
On-Board Measures	Longitudinal Stick Average Position	6	-.54	-.52	.72	.31	.85	1															
On-Board Measures	Longitudinal Stick Mean Crosses	7	.68	.73	-.56	-.28	-.15	-.59	1														
On-Board Measures	Longitudinal Stick Rate Sign Changes	8	.49	.54	-.15	-.02	.38	-.08	.81	1													
On-Board Measures	Longitudinal Stick Steady Time	9	-.04	-.14	-.33	-.22	-.81	-.48	-.36	-.78	1												
Opinion	Work Load	10	-.28	-.28	.33	.18	.68	.39	.17	.44	-.67	1											
Opinion	Performance	11	-.27	-.12	-.08	-.03	.44	.17	.24	.30	-.56	.73	1										
Frequency Measures: Long. Stick Power Spectral Density	Median Frequency	12	.62	.68	-.65	-.30	-.58	-.84	.82	.37	.07	-.17	-.14	1									
Frequency Measures: Long. Stick Power Spectral Density	Cutoff Frequency	13	.77	.79	-.59	-.26	-.25	-.64	.96	.77	-.26	-.03	.04	.80	1								
Frequency Measures: Long. Stick Power Spectral Density	Standard Deviation	14	.78	.77	-.57	-.25	-.17	-.56	.91	.81	-.31	.03	.02	.65	.96	1							
Frequency Measures: Long. Stick Power Spectral Density	Mode Frequency	15	.72	.15	-.09	.07	-.27	-.42	.41	.07	-.03	.25	.45	.66	.24	.05	1						
Frequency Measures: Long. Stick Power Spectral Density	Mean Frequency	16	.67	.70	-.61	-.24	-.47	-.81	.91	.53	-.07	-.03	.18	.97	.89	.78	.61	1					
Frequency Measures: Long. Stick Vs. Pitch Rate Cross Spectral Density	Median Frequency	17	.56	.62	-.57	-.23	-.61	-.83	.74	.29	.11	-.21	.13	.99	.72	.56	.71	-.94	1				
Frequency Measures: Long. Stick Vs. Pitch Rate Cross Spectral Density	Cutoff Frequency	18	.64	.67	-.46	-.17	.09	-.53	.93	.83	-.42	.12	.20	.73	.93	.92	.24	.84	.68	1			
Frequency Measures: Long. Stick Vs. Pitch Rate Cross Spectral Density	Standard Deviation	19	.81	.83	-.50	-.22	-.11	-.50	.93	.85	-.42	.08	.09	.70	.94	.96	.18	.81	.63	.95	1		
Frequency Measures: Long. Stick Vs. Pitch Rate Cross Spectral Density	Mean Frequency	20	.59	.64	-.60	-.25	-.53	-.83	.82	.42	-.01	-.07	.22	.97	.79	.68	.65	.97	.97	.79	.74	1	
Frequency Measures: Long. Stick Vs. Pitch Rate Cross Spectral Density	Mode Frequency	21	.37	.38	-.51	-.28	-.65	-.71	.46	-.05	.31	-.19	-.04	.81	.40	.24	.75	.74	.86	.38	.33	.81	1
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

the larger amplitudes. Stick rate correlated with stick steady time (9) in a negative sense. This is natural since the steady time measure is based on the absence of rates above .5% total travel per second. Both stick rate and stick position correlate negatively with median frequency of control motion. This indicates that the large rates and amplitudes are associated with the low frequencies. The measure of longitudinal stick mean crosses was originally employed to find a "poor man's power spectral density." The correlation was even better than had been expected, and since it is easy to calculate it can serve adequately to detect frequency differences in many problems.

The measures of pilot opinion of work load and performance correlated at .73 with one another. The work-load ratings correlated at .68 and -.67 respectively with stick rate and stick steady time. These are the only predictors of pilot opinion discovered in these data. Pilot opinion of performance does not correlate significantly with actual performance, and the frequency measures do not bear a significant relationship to the opinion measures. This lack of correlation between opinion and other measures is due primarily to the variability of the opinion data.

Table VI is the lateral hover correlation matrix. It shows that lateral position error measures correlate negatively with opinion of work load and performance. The reason is that opinion measures are for the aircraft as a whole and are not limited to the lateral degrees of freedom as are the other measures. This also indicates that the pilot is not sensitive to the exact precision of his performance. The .58 correlation of opinion of work load with lateral stick rate and -.62 with steady time again indicates the influence of control activity on pilot opinion. The measure of mean crosses for lateral stick tends to confirm the longitudinal data which show a high correlation with many of the frequency measures taken from the power spectral density calculations. In addition, correlations among the frequency measures themselves are also generally quite high.

TABLE VI. HOVER - LATERAL CORRELATION MATRIX

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Camera	Lateral Position Standard Deviation	1	1																				
Camera	Lateral Position Offset	2	.81	1																			
On-Board Measures	Roll Rate Standard Deviation	3	.61	.10	1																		
On-Board Measures	Roll Rate IAE	4	.26	.15	.99	1																	
On-Board Measures	Lateral Stick Average Rate	5	.19	.10	.45	.49	1																
On-Board Measures	Lateral Stick Average Position	6	.17	.18	.82	.83	.84	1															
On-Board Measures	Lateral Stick Mean Crosses	7	.13	-.05	.63	.58	.32	-.23	1														
On-Board Measures	Lateral Stick Rate Sign Changes	8	.00	-.17	-.26	-.23	.36	-.02	.66	1													
On-Board Measures	Lateral Stick Steady Time	9	.11	.08	-.29	-.32	-.87	-.60	-.50	.66	1												
Opinion	Work Load	10	.27	.61	.06	.07	.58	.29	.47	.36	-.62	1											
Opinion	Performance	11	-.22	-.55	-.77	-.09	.34	.10	.43	.51	-.48	.73	1										
Frequency Measures: Lat. Stick Power Spectral Density	Median Frequency	12	.11	.06	-.52	-.46	.46	-.08	.97	.63	-.61	.54	.49	1									
Frequency Measures: Lat. Stick Power Spectral Density	Cutoff Frequency	13	.09	-.03	-.54	-.48	-.41	-.13	.97	.73	-.61	.45	.33	.95	1								
Frequency Measures: Lat. Stick Power Spectral Density	Standard Deviation	14	-.04	-.21	-.59	-.55	.17	.32	.86	.87	-.48	.36	.48	.78	.88	1							
Frequency Measures: Lat. Stick Power Spectral Density	Mode Frequency	15	.26	-.20	-.26	-.29	.37	.15	.45	.41	-.36	.33	.65	.54	.39	.36	1						
Frequency Measures: Lat. Stick Power Spectral Density	Mean Frequency	16	.04	-.09	-.56	-.50	.41	-.14	.98	.69	-.60	.52	.37	.97	.99	.85	.41	1					
Frequency Measures: Lat. Stick Vs. Roll Rate Cross Spectral Density	Median Frequency	17	.21	.03	-.40	-.34	.56	-.08	.92	.63	-.67	.55	.58	.97	.88	.72	.62	.90	1				
Frequency Measures: Lat. Stick Vs. Roll Rate Cross Spectral Density	Cutoff Frequency	18	.60	.20	-.01	.08	.55	.18	.68	.55	-.68	.44	.30	.70	.70	.53	.92	.68	.71	1			
Frequency Measures: Lat. Stick Vs. Roll Rate Cross Spectral Density	Standard Deviation	19	.57	.13	.02	.11	.50	.16	.64	.67	-.67	.42	.40	.62	.65	.63	.05	.61	.65	.94	1		
Frequency Measures: Lat. Stick Vs. Roll Rate Cross Spectral Density	Mean Frequency	20	.33	.09	-.42	-.34	.49	.00	.94	.61	-.63	.49	.46	.97	.90	.72	.45	.90	.97	.81	.74	1	
Frequency Measures: Lat. Stick Vs. Roll Rate Cross Spectral Density	Mode Frequency	21	.20	.08	-.42	-.36	.51	.04	.90	.58	-.62	.41	.46	.94	.87	.73	.55	.88	.96	.65	.61	.95	1
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

HOVER TURNS

Objective Data

The error data are again presented in the form of isometric figures. In this case the error measures are broken down into north-south and east-west errors rather than into lateral and longitudinal errors, because all turns were started with the aircraft facing north. The analyses of variance results are tabulated in Table VII. The principal difference between this table and Table IV (showing the hover results) is the inclusion of the test for direction of turn. This allows testing of whether or not a particular parameter differs in a right turn vs. a left turn.

Offset Errors

The offset error data are shown in Figure 36. As in the hover task, these error measures are based on using the initial point in the trial as the error reference, thus eliminating the initial mispositioning of the aircraft from the position error. The effect of configuration produced significant differences only along the east-west dimension, with the wing-and-tail-removed configuration showing a smaller position error. Left turns were significantly more precise than right turns along all dimensions. These effects might be explained by the turn technique employed by all three pilots. Although prior to the flight test they felt that turns could be made about the rotor head, in practice there was a tendency to back the aircraft off the ground reference point until the point could be seen from the cockpit. This resulted in right turns with left sideward velocity and left turns with right sideward velocity. In a left turn the pilot (seated on the right) is in a better position to see the projected path of the aircraft than in a right turn. The smaller east-west error with wing and tail off can be attributed to the same factors which produced a more precise lateral position for this configuration in the hover task.

Standard Deviation

Figure 37 shows the results for the standard deviation measure of position. Again, the wing-and-tail-off configuration is capable of more precise turns as measured in the east-west direction. In addition, both east-west and north-south errors are less in the left turns than in the right turns. These effects are similar to those observed in the offset error data, and the same explanations apply.

TABLE VII. HOVERING TURNS — ANALYSES OF VARIANCE RESULTS

PARAMETERS	Configuration A	Turn Direction B	Pilots C	A x B	A x C	B x C	A x B x C
CAMERA DATA							
North-South Position							
Offset Error	N.S.	X	X	N.S.	X	X	X
Standard Deviation	N.S.	X	X	N.S.	X	X	X
East est Position							
Offset Error	X	X	N.S.	X	N.S.	X	N.S.
Standard Deviation	X	X	X	X	N.S.	X	N.S.
Vertical Position							
Offset Error	N.S.	X	X	X	X	N.S.	X
Standard Deviation	N.S.	N.S.	N.S.	N.S.	X	N.S.	X
TAPE DATA							
Roll Rate Standard Deviation	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Pitch Rate Standard Deviation	X	X	X	N.S.	N.S.	N.S.	N.S.
Yaw Rate Standard Deviation	N.S.	N.S.	X	N.S.	X	N.S.	N.S.
Longitudinal Cyclic							
Average Rate	X	N.S.	X	N.S.	N.S.	N.S.	N.S.
Average Position	X	X	N.S.	N.S.	N.S.	N.S.	N.S.
Steady Time	X	X	X	N.S.	N.S.	N.S.	N.S.
Lateral Cyclic							
Average Rate	X	N.S.	X	N.S.	N.S.	N.S.	N.S.
Average Position	X	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Steady Time	N.S.	N.S.	X	N.S.	N.S.	N.S.	X
Pedals							
Average Rate	X	N.S.	X	N.S.	X	N.S.	N.S.
Average Position	X	X	N.S.	X	X	N.S.	N.S.
Steady Time	X	X	N.S.	X	N.S.	X	X
Collective							
Average Rate	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Average Position	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Steady Time	N.S.	N.S.	X	N.S.	X	N.S.	X

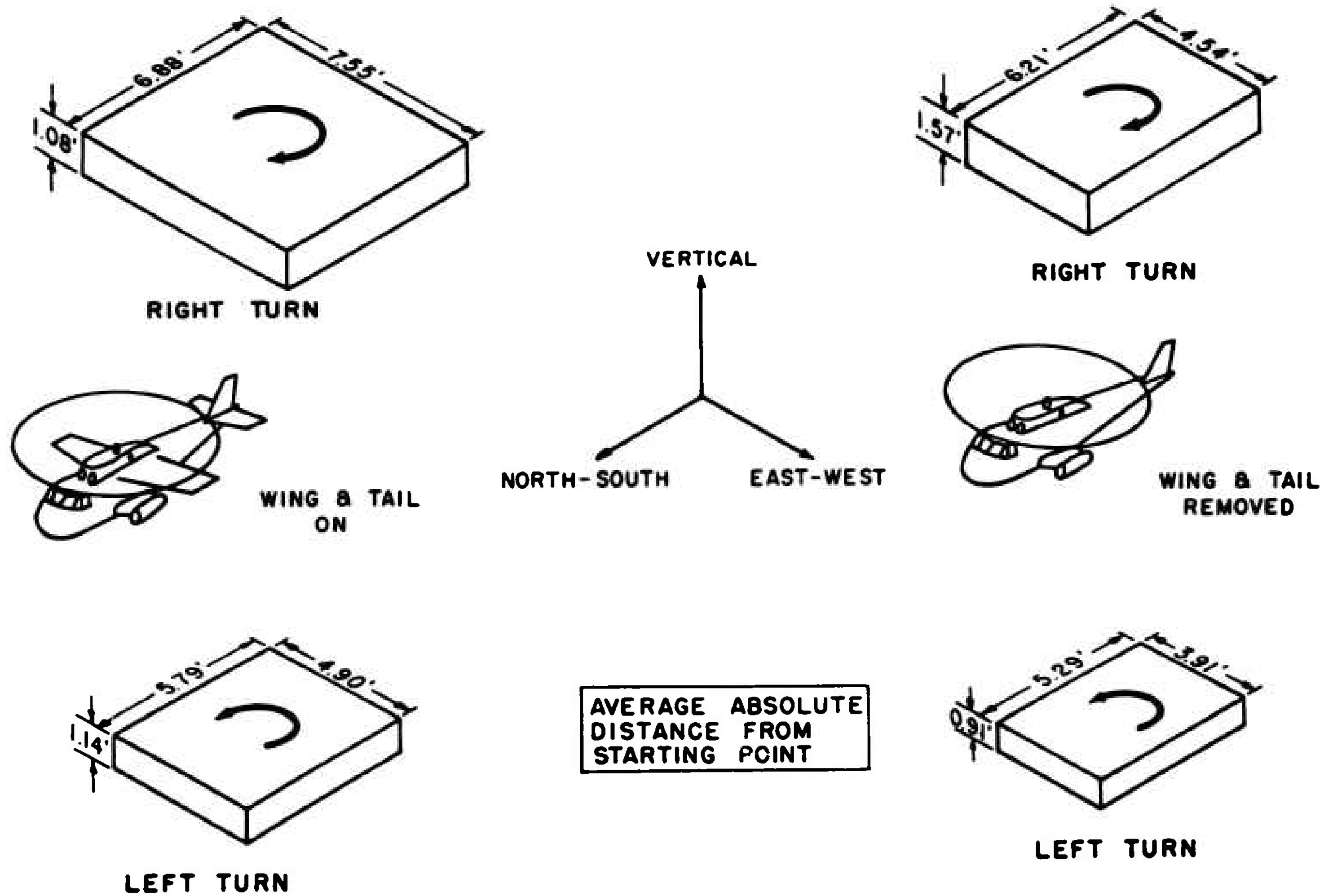


FIGURE 36. HOVER TURNS — OFFSET ERRORS

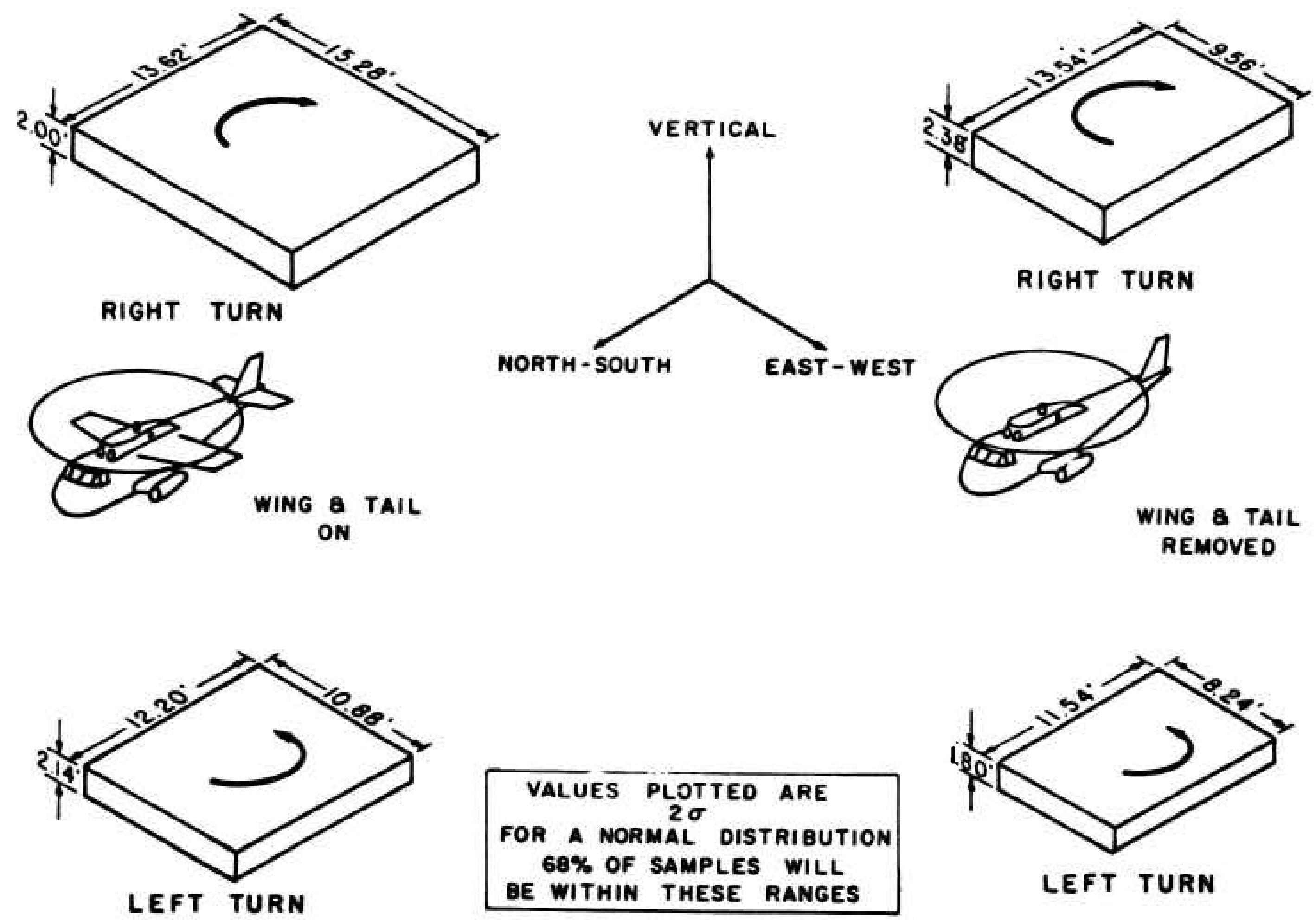


FIGURE 37. HOVER TURNS — STANDARD DEVIATIONS OF POSITION

Work-Load Measures

Attitude Rate

To examine the aircraft attitude activity, standard deviations of the rates of roll, pitch, and yaw are plotted in Figure 38. The values shown are $\pm 1\sigma$, indicating that, for a normal distribution, 68% of the samples fall within this range.

The only significant differences are found in the pitch rate data. Pitch activity is significantly greater with the wing and tail on. This finding is consistent with many other indications of random pitching motion of this compound configuration and can be explained by the unsteady effects of downwash on the horizontal stabilizer. The pitch rate measure also shows more activity in the right turn than in the left turn. This is perhaps indicative of the fact that when the pilot has a good view of the situation (i.e., turning to the left), he produces smaller errors and does not require large pitch changes for corrections.

Control Positions

Figures 39 and 40 show the means, standard deviations, and maximum values of longitudinal cyclic, lateral cyclic, collective pitch and pedal positions measured in the hover turn tasks with both configurations.

The characteristic forward shift of longitudinal cyclic with wing and tail on is present in both left and right turns. Accompanying this are greater standard deviations and maximum input values. These reflect the requirement for more longitudinal stick activity to offset destabilizing effects of the main rotor downwash on the horizontal stabilizer. Lateral cyclic shows a slightly larger standard deviation value in the compound configuration than with wings and tail off. This is probably due to the cross coupling of pitch with roll and yaw and to the disturbances generated in roll by the pilot's longitudinal control inputs which contain small lateral components.

Pedal inputs show the effect of turn direction, but do not appear to reveal differences due to configuration, except perhaps in the maximum extent of control utilized. It is important to remember, however, that the maximum value represented is the one-time maximum used by one of the pilots in one of his five trials and not an average. The collective control plots show a consistent difference in mean collective position for the right vs. the left

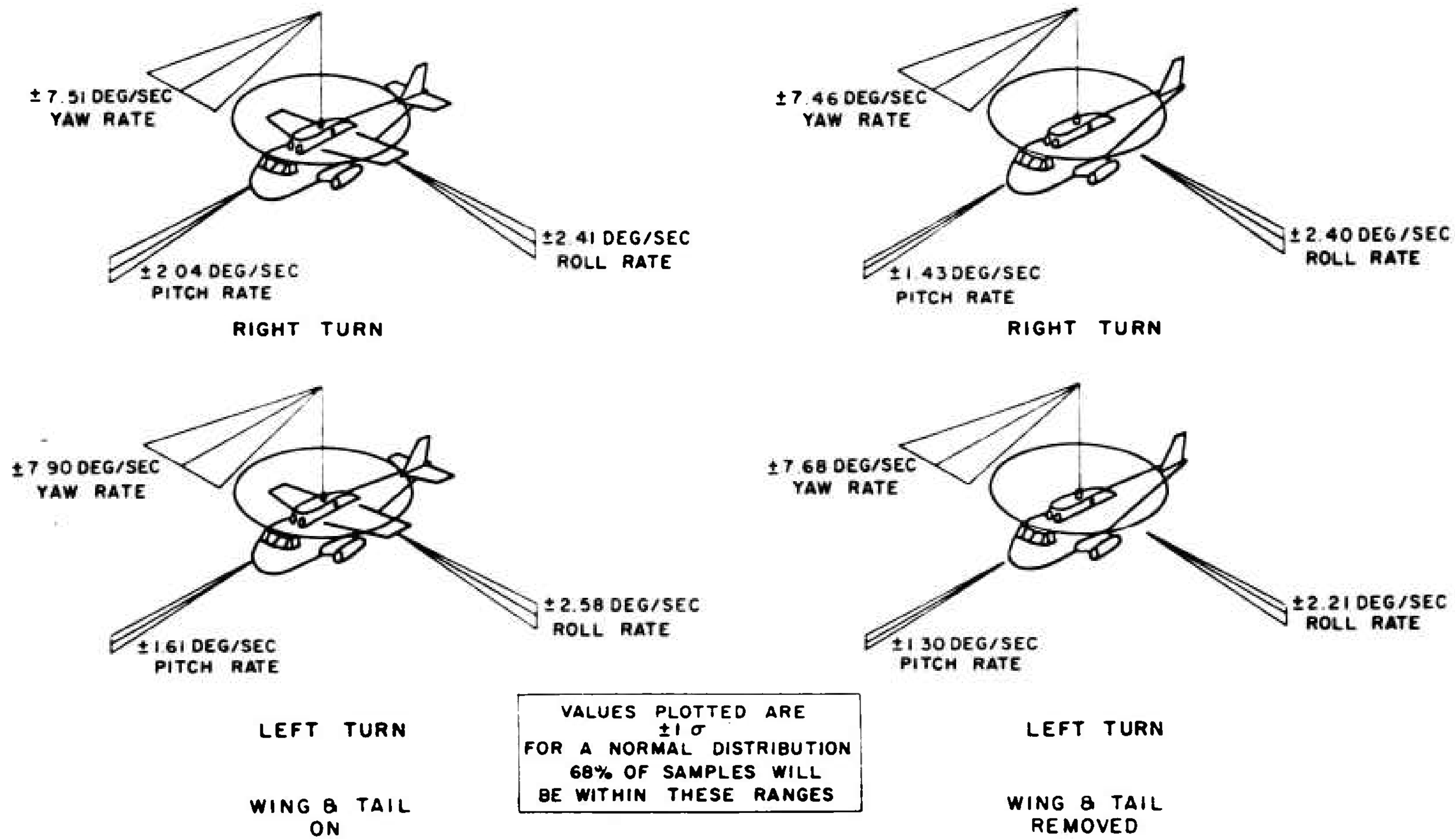


FIGURE 38. HOVER TURNS — ATTITUDE RATES

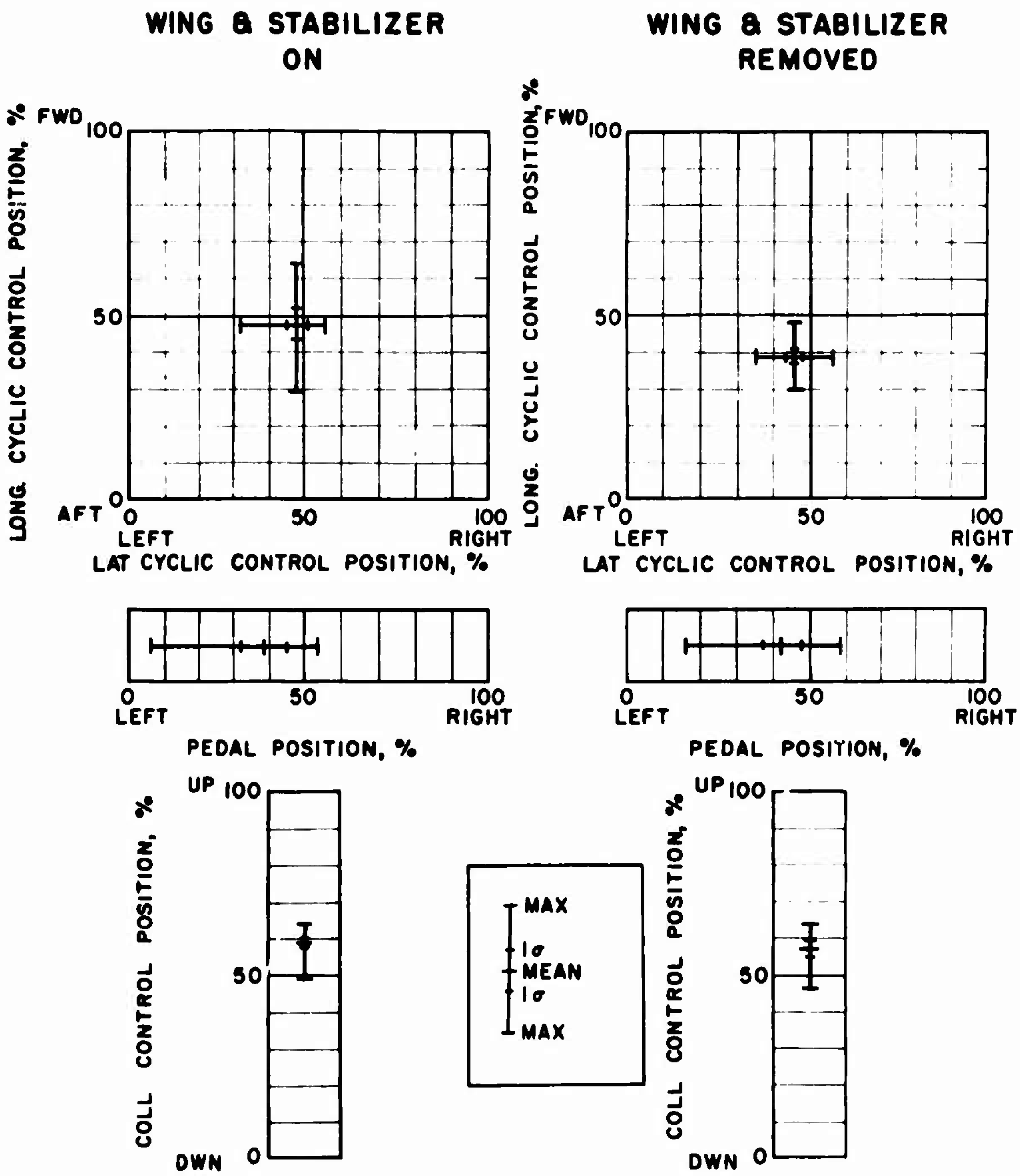


FIGURE 39. RIGHT HOVER TURN — CONTROL POSITIONS

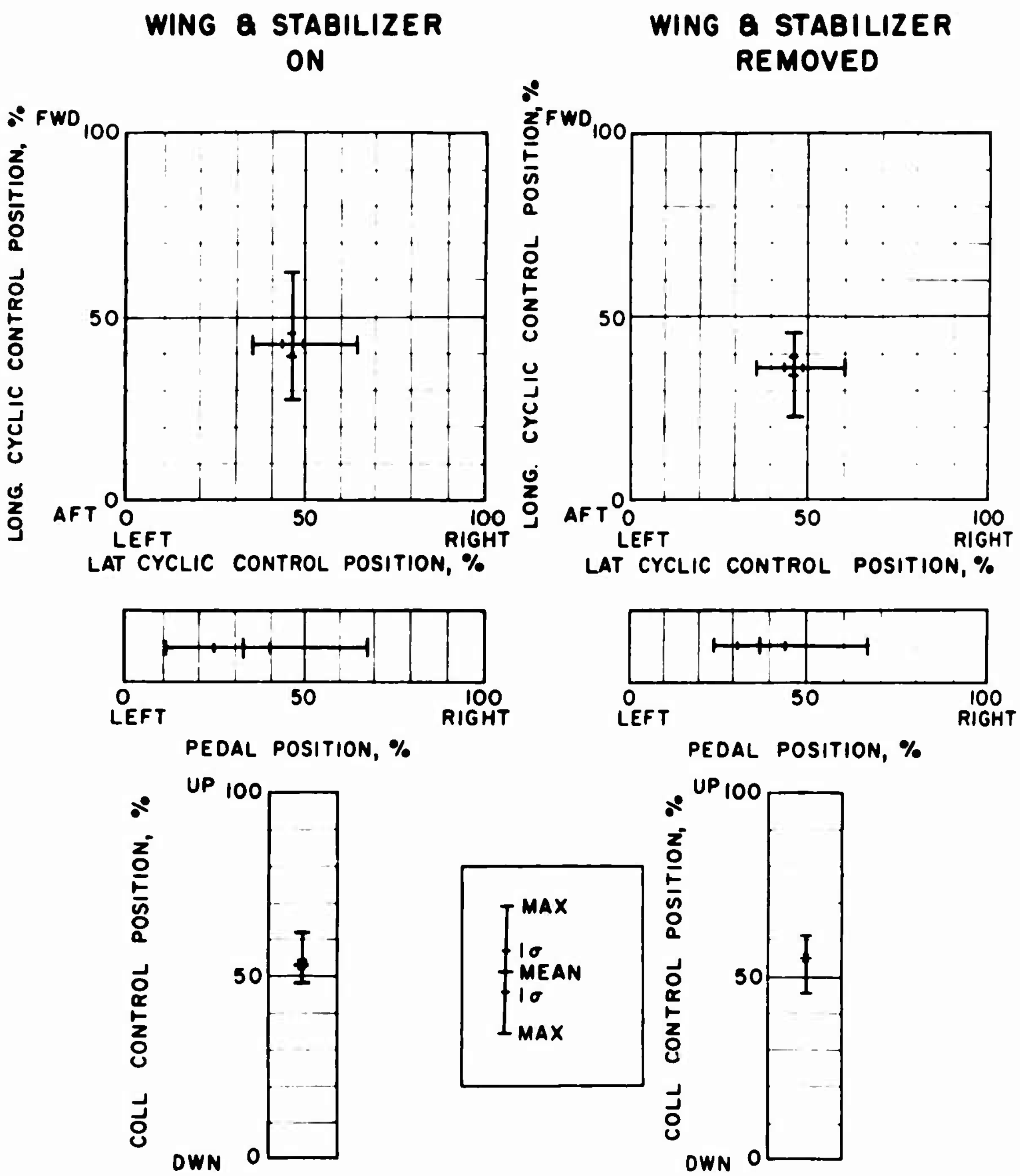


FIGURE 40. LEFT HOVER TURN — CONTROL POSITIONS

turns. This is the result of the fuel control overshoot with a change in power requirement. For example, in the left turn case, the tail rotor absorbs power from the system and thereby tends to slow down the main rotor. The governor senses the rpm drop and compensates by adding power to the system. This compensation tends to be too large, and hence the pilot must reduce collective to keep from climbing.

Control Activity

Figure 41 shows the measures of average control rate and position for the hover turns. The analysis of variance shows that the wing-and-tail-on configuration results in higher rates and larger amplitude control inputs for all controls except collective. This is a clear indication that the pilot is working harder physically to compensate for the unsteady effects of the wing and horizontal stabilizer

The effect of turn direction is not evident in the control rate measure. However, longitudinal control amplitude is slightly greater in a right turn and pedal amplitude is slightly greater in a left turn.

Power Spectral Density

Configuration differences are evident only for longitudinal control inputs. With the wing and tail on there is evidence of the same low-frequency random inputs which were seen in hover. These random inputs are not evident without the wing and tail, but there is greater relative power near .4 cps. These results must be considered along with the control rate and amplitude discussed in the previous section. Both rate and amplitude are greater with the winged configuration. This would indicate that the low-frequency random inputs have large amplitude and rate while the inputs generated at .4 cps with the wing and tail off are small corrections.

Lateral cyclic, collective and pedals do not appear to differ with configuration. Turn direction does not seem to have a general effect, but Pilot 2 shows a difference in his longitudinal control behavior in right and left turns. Pilot differences are very recognizable throughout this type of data. Pilot 1 generally has lower frequency content than Pilots 2 and 3. The intertrial variability is also quite high, possibly indicating that the pilot is changing his control strategy. The danger of accepting any single trial as indicative of the underlying process is clear. Often the intertrial variability exceeds the effect due to vehicle changes.

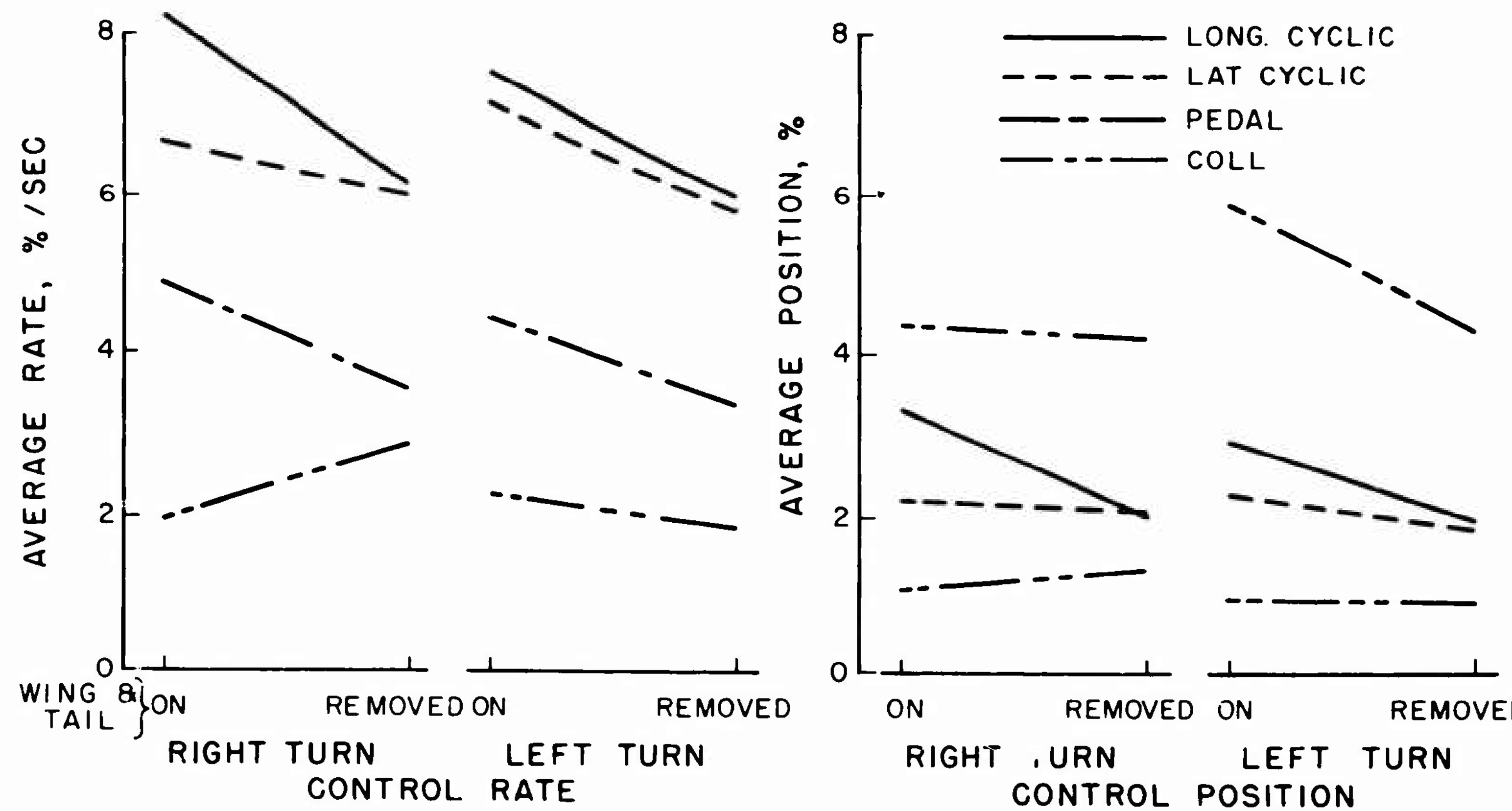


FIGURE 41. HOVER TURNS — CONTROL RATE AND AMPLITUDE

Pilot Opinion Data

The diversity of pilot opinions is shown in Figure 42. The upper two portions of this figure show the performance and work-load ratings given by each of the pilots for the hovering turn trials. The lower portion of this figure represents the Cooper-Harper rating values taken at the end of the flights which included both hover and hovering turns. Hence, these ratings are identical to those shown at the bottom of Figure 35.

For both performance and work-load ratings, the effect of wing and tail produces markedly different ratings by the three pilots. Pilot 1 consistently rates the wing-and-tail-off configuration as better and easier than the configuration with wing and tail on. Pilot 2 rates the same conditions oppositely. Pilot 3 shows virtually no difference in ratings as the configuration was changed.

The Cooper-Harper ratings show Pilot 1 favoring the wing-and-tail-on configuration, Pilot 2 showing equal ratings and Pilot 3 preferring the wing-and-tail-off condition.

It would be difficult to imagine a set of data harder to interpret than this. This diversity of opinion reflects the unreliability of using only pilot opinion as the measure of aircraft flying and handling qualities. It highlights the need for development of a method of flying and handling qualities evaluation based on a combination of objective measures and pilot acceptance.

Evaluation

Although the effect of configuration shows up to some extent in the precision measures, its major influence was on the measures of pitch attitude rate and control activity. The pitch rate measures were greater for the wing-and-tail-on configuration, indicating that the aircraft was being disturbed longitudinally. The measures of control activity reliably show this effect for longitudinal, lateral, and pedal rates and positions. The power spectral density data for longitudinal stick also show the random low-frequency inputs typical of the wing-and-tail-on configuration. The pilot opinion data show the greatest diversity possible with three pilots, thus again demonstrating the need for a truly reliable and consistent method of flying and handling qualities evaluation.

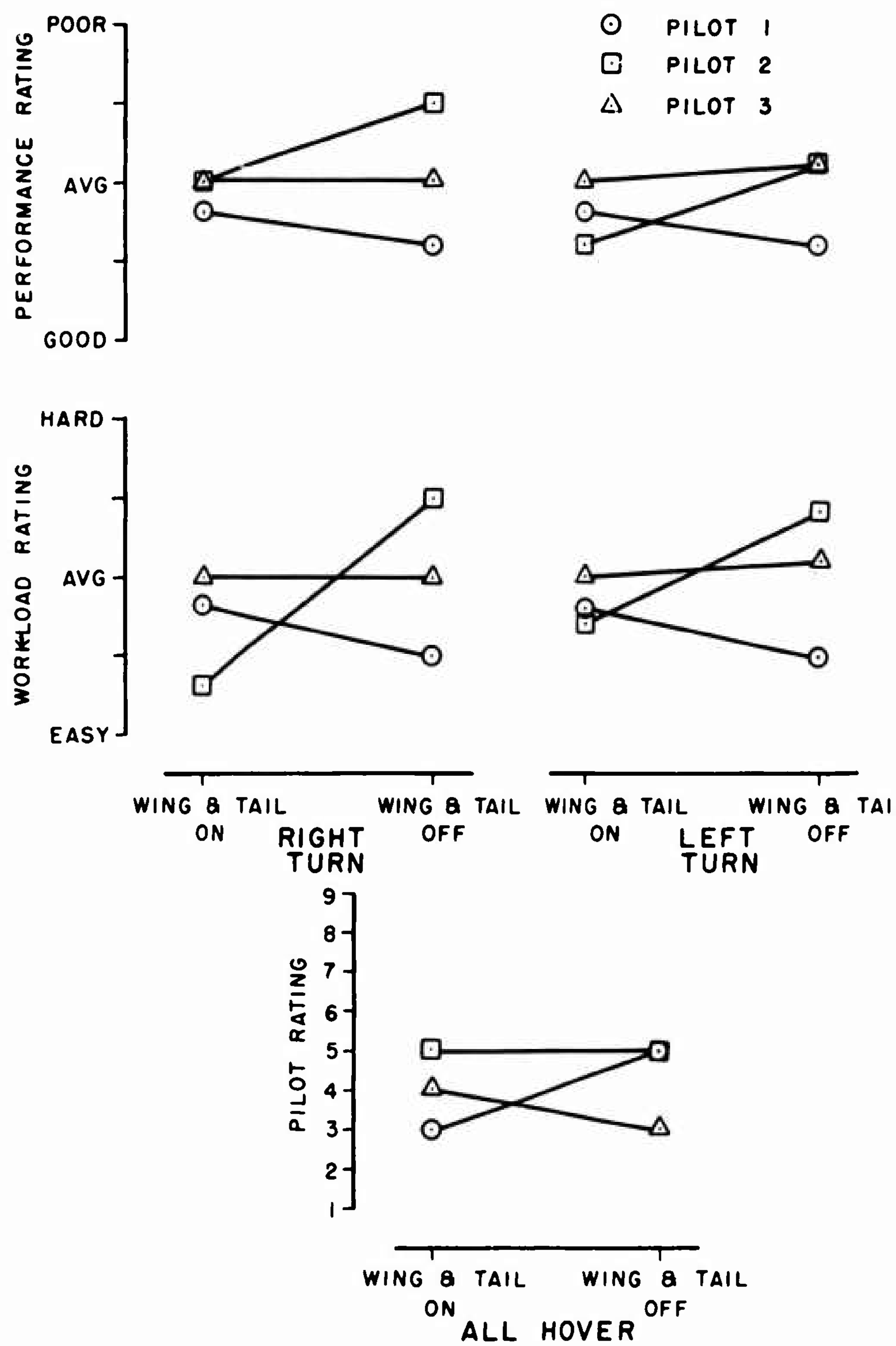


FIGURE 42. HOVER TURNS — PILOT OPINION DATA

AIR TAXI

The air-taxi data were collected in two parts, constant heading and heading along course. The constant heading tests involved forward, rearward, left sideward and right sideward flight along the air-taxi course, Figure 6. The air-taxi-along-course task consisted of forward flight along north, south, east and west legs of the same course. A review of the data showed that results from along-the-course-trials were sufficiently similar to the results of the forward flight legs of the constant heading case to warrant the presentation of the latter only.

Tables VIII and IX list the results of the analyses of variance tests which were applied separately to the forward-rearward data and to the left-right sideward flight data. These tables allow determination of the statistical significance of the effects of configuration, direction and pilots.

Objective Data

Figures 43, 44 and 45 show the measures of air-taxi precision. The wing-and-tail-on configuration is shown on the left side of each of these figures. Lines are projected from each aircraft figure showing the direction of motion and a graphical representation of the magnitudes of measured error. For the fore-aft cases the data shown are the lateral and vertical deviations; in the sideward flight cases the data represent the longitudinal and vertical deviations.

Offset Error

As in the hover trials, offset error is defined as the deviation which occurred from the initial point selected by the pilot. For the air-taxi trials this initial point established the end point of the line to be followed. Figure 43 represents the error in each of the four directions flown. By referring to this figure and Tables VIII and IX, it is possible to tell which of the differences are statistically significant.

The lateral error in fore-aft flight is significantly affected by configuration, with greater precision occurring in the wing-and-tail-off conditions. Configuration produces a similar effect on the fore-aft errors which occur in sideward flight. In addition, vertical error was less in sideward flight with the wing and tail off.

As one would expect, the forward air taxi is more precise than the rearward; however, the difference between right and left sideward flight fails to reach significance.

TABLE VIII. AIR TAXI — ANALYSES OF VARIANCE RESULTS, FORWARD-REARWARD

PARAMETERS	Configuration A	Fore-Aft B	Pilots C	A x B	A x C	B x C	A x B x C
CAMERA DATA							
Lateral Position							
Offset Error	X	X	X	N.S.	N.S.	X	X
Standard Deviation	X	X	N.S.	N.S.	X	N.S.	N.S.
Vertical Position							
Offset Error	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.
Standard Deviation	N.S.	X	X	N.S.	N.S.	X	N.S.
TAPE DATA							
Pitch Rate Standard Deviation	X	N.S.	N.S.	N.S.	X	N.S.	X
Roll Rate Standard Deviation	X	X	X	N.S.	X	N.S.	N.S.
Yaw Rate Standard Deviation	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.
Yaw Average Error	X	N.S.	N.S.	N.S.	X	N.S.	N.S.
Longitudinal Cyclic							
Average Rate	X	N.S.	X	N.S.	X	N.S.	N.S.
Average Position	X	X	X	X	X	X	X
Steady Time	X	N.S.	X	N.S.	X	N.S.	N.S.
Lateral Cyclic							
Average Rate	N.S.	X	X	N.S.	X	N.S.	N.S.
Average Position	X	X	X	N.S.	X	N.S.	N.S.
Steady Time	X	N.S.	X	N.S.	X	N.S.	X
Pedals							
Average Rate	N.S.	X	X	N.S.	X	N.S.	N.S.
Average Position	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Steady Time	N.S.	N.S.	X	N.S.	X	N.S.	N.S.
Collective							
Average Rate	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.
Average Position	N.S.	N.S.	X	X	N.S.	N.S.	N.S.
Steady Time	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.

TABLE IX. AIR TAXI — ANALYSES OF VARIANCE RESULTS, SIDEWARD LEFT-RIGHT

PARAMETERS	Configuration A	Left Right B	Pilots C	A x B	A x C	B x C	A x B x C
CAMERA DATA							
Longitudinal Position							
Offset Error	X	N.S.	X	N.S.	X	X	N.S.
Standard Deviation	N.S.	N.S.	X	N.S.	X	X	N.S.
Vertical Position							
Offset Error	X	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Standard Deviation	X	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
TAPE DATA							
Pitch Rate Standard Deviation	X	X	X	N.S.	X	N.S.	N.S.
Roll Rate Standard Deviation	X	N.S.	X	X	N.S.	N.S.	N.S.
Yaw Rate Standard Deviation	N.S.	N.S.	X	N.S.	X	N.S.	N.S.
Yaw Average Error	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.
Longitudinal Cyclic							
Average Rate	X	X	X	N.S.	X	N.S.	N.S.
Average Position	X	X	N.S.	N.S.	X	N.S.	N.S.
Steady Time	N.S.	X	X	N.S.	X	N.S.	N.S.
Lateral Cyclic							
Average Rate	X	N.S.	X	X	X	N.S.	N.S.
Average Position	X	N.S.	X	X	N.S.	N.S.	N.S.
Steady Time	N.S.	N.S.	X	N.S.	X	N.S.	N.S.
Pedals							
Average Rate	N.S.	N.S.	X	N.S.	X	X	N.S.
Average Position	X	N.S.	X	N.S.	N.S.	N.S.	N.S.
Steady Time	N.S.	N.S.	X	N.S.	N.S.	X	N.S.
Collective							
Average Rate	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.
Average Position	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.
Steady Time	N.S.	N.S.	X	N.S.	N.S.	N.S.	N.S.

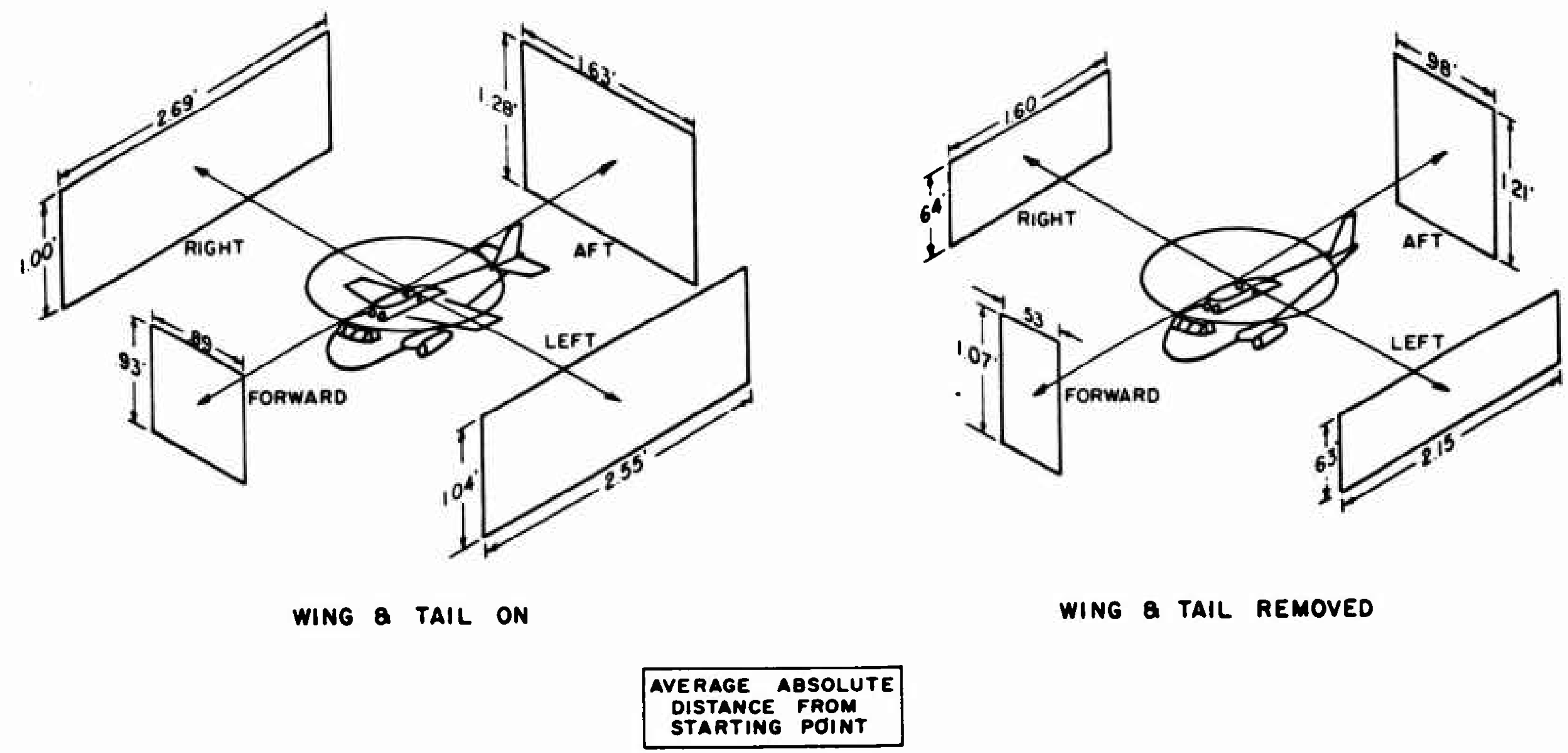
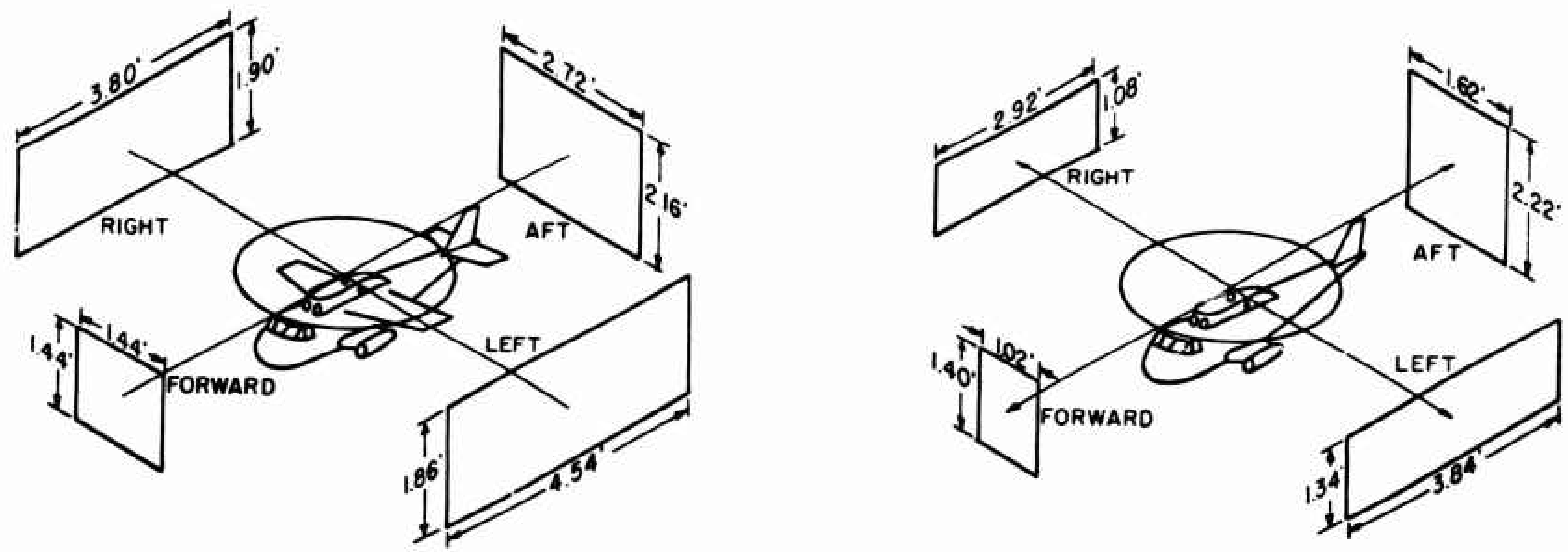


FIGURE 43. AIR TAXI — OFFSET ERRORS

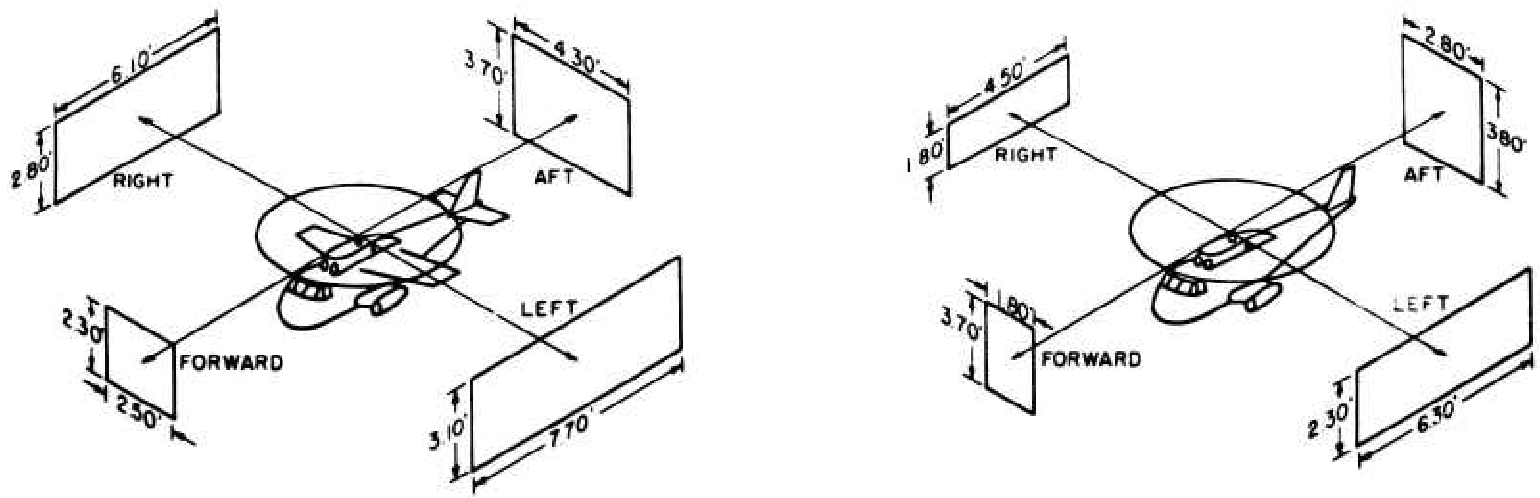


WING & TAIL ON

WING & TAIL REMOVED

VALUES PLOTTED ARE
2σ
FOR A NORMAL DISTRIBUTION
68% OF SAMPLES WILL
BE WITHIN THESE RANGES

FIGURE 44. AIR TAXI — STANDARD DEVIATIONS OF POSITION



WING & TAIL ON

WING & TAIL REMOVED

FIGURE 45. AIR TAXI — AVERAGE PEAK ERRORS

Standard Deviations

The standard deviations of position, Figure 44, are indicative of the spread of the error distributions. The shapes of the standard deviation envelopes are quite similar to those shown in the previous figure. The major difference is the failure of the fore-aft errors in sideward flight of reach statistical significance.

Peak Errors

Figure 45 shows the average error envelopes which were measured for flight in all four directions. These data confirm the offset error and standard deviation data which indicate a clear superiority of the wing-and-tail-off configuration for longitudinal and lateral precision air taxi. Comparing the air taxi with the hover performance, it is interesting to note that the apparent advantage of the wing-and-tail-on configuration for fore-aft precision in hover does not exist in the air-taxi data. The difference is perhaps due to non-occurrence in sideward flight of the longitudinal speed stability postulated as the explanation for the hover data.

Work-Load Measures

Attitude Rates

Figures 46 and 47 show the roll, pitch and yaw rates measured in fore-aft flight and in sideward flight. These standard deviation values reflect the attitude activity which occurred and are considered to be representative of the difficulty of the control task.

For the fore-aft tasks, Figure 46 indicates that all attitude rates were less with the wing and tail removed. These differences were significant for the roll and pitch rate measures. However, the yaw rate differences were not sufficiently large to reach significance. Roll rate differed significantly with direction. Forward flight produced less roll rate than rearward flight.

The sideward flight cases show somewhat the same effects. Pitch rate activity is greater with the wing and stabilizer on, and rate is significantly greater in this configuration in spite of the small reversal which occurs in left sideward flight. Yaw rate again fails to reach significance.

These data tend to support the contention that the aircraft is easier to fly in low-speed tasks with the wing and tail off. This again seems

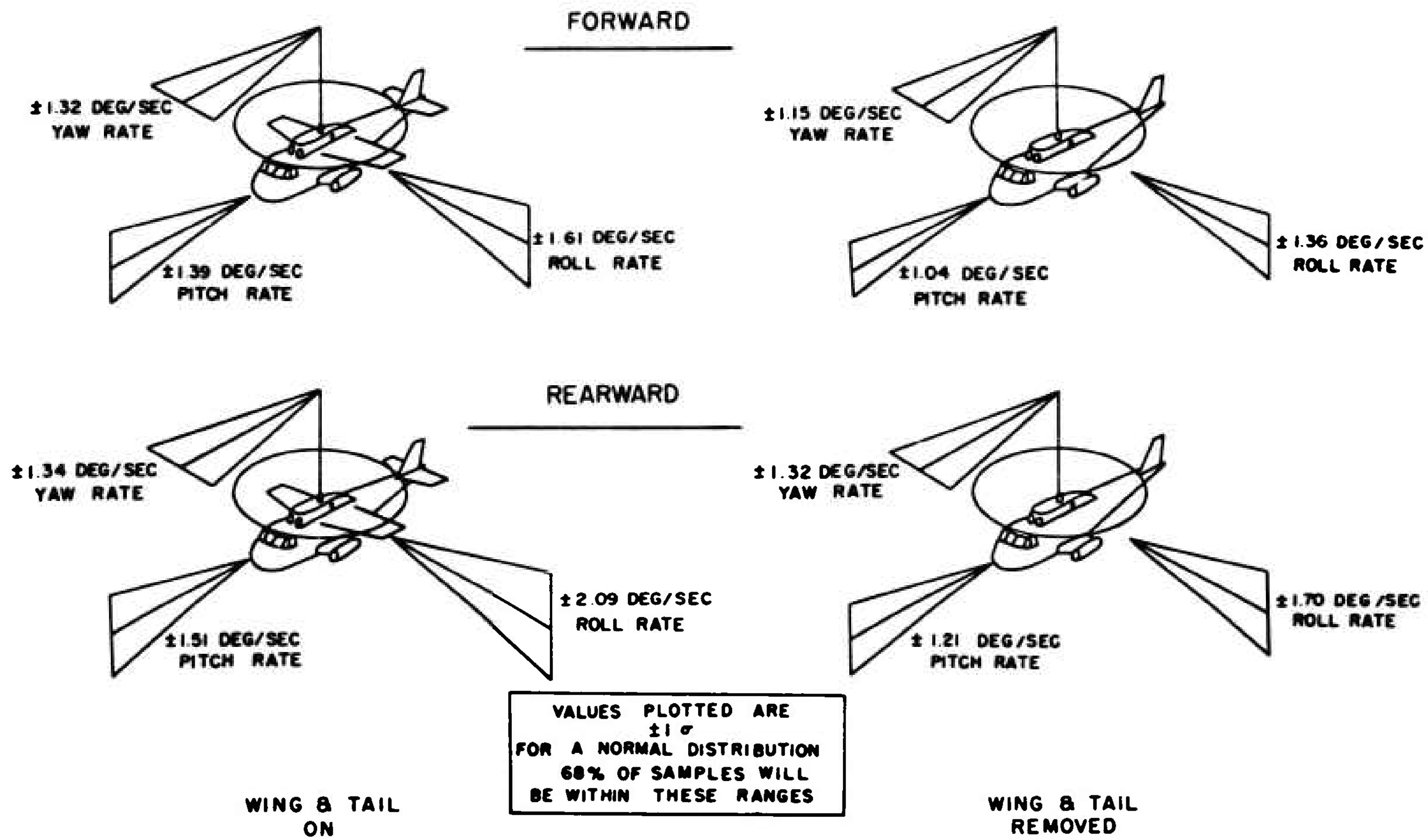


FIGURE 46. AIR TAXI — FORE-AFT ATTITUDE RATES

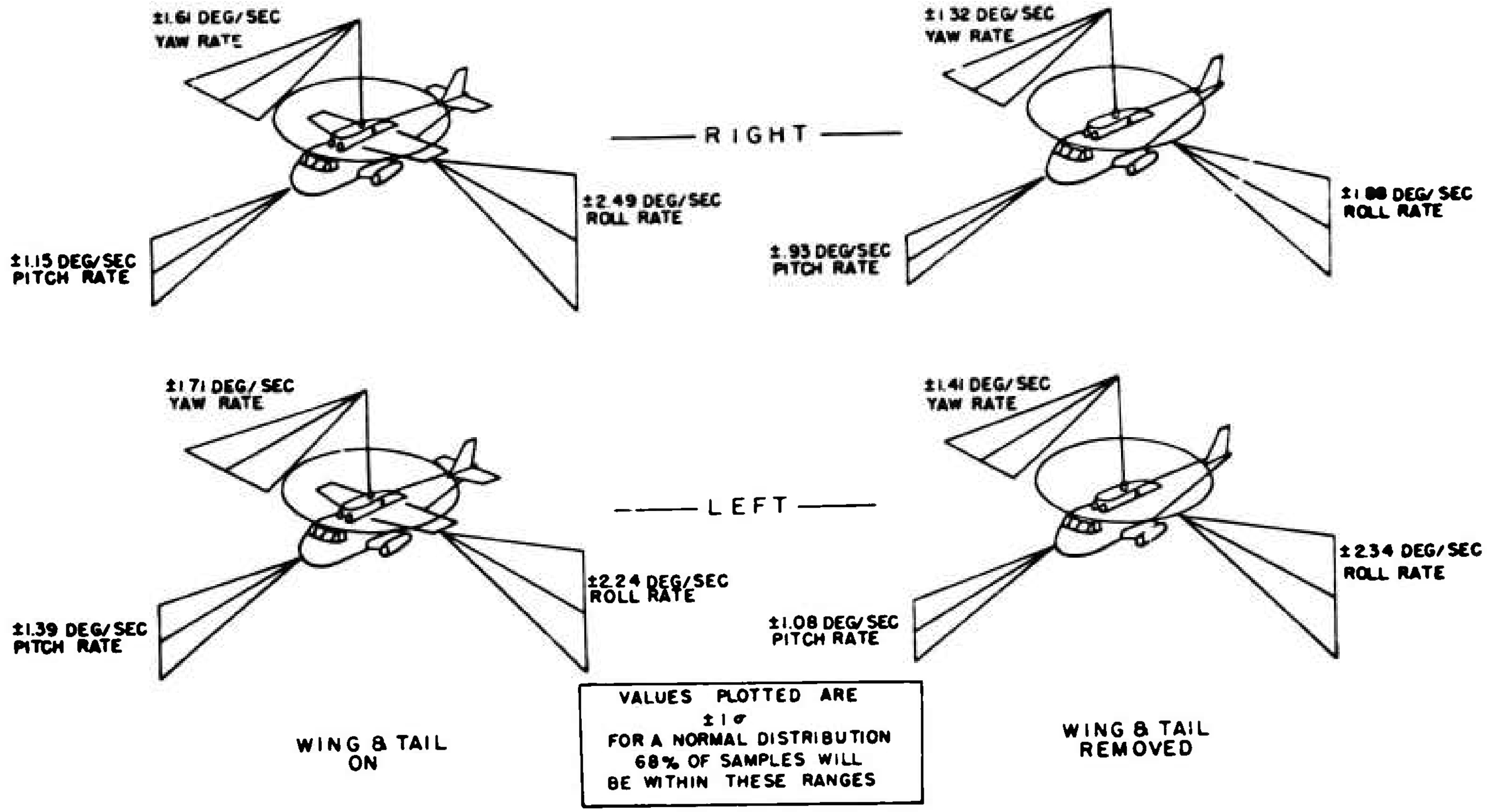


FIGURE 47. AIR TAXI — LATERAL ATTITUDE RATES

to be due to the unsteady aerodynamic effects of the rotor downwash on the wing and horizontal stabilizer.

Control Positions

Figures 48 through 51 show the control position measures for forward, rearward, and sideward flight conditions. Each of these figures shows the characteristic forward shift of the longitudinal stick with the wing and horizontal stabilizer on. Also characteristic of this configuration are the increased standard deviations and maximum peaks of longitudinal control. The control inputs for the other configuration appear to be better balanced in magnitude between longitudinal and lateral cyclic. The pedal and collective plots do not show the effects of configuration.

Control Activity

Measures of control rate, control amplitude, and control steady time are presented in Figures 52, 53, and 54.

The first of these, control rate, most clearly shows the effect of configuration on longitudinal stick activity. The rate increases significantly with the wing and tail on. There is also a similar lateral effect which is significant in sideward flight; however, collective and pedals are unaffected.

The longitudinal cyclic and lateral cyclic amplitudes were found to vary significantly with configuration for both fore-aft and sideward flight. Although the lateral differences appear to be quite small, and actually reverse in one case, the overall effect of wing and tail is to increase the control input amplitude. Pedal amplitude is significantly affected in the same manner for sideward flight.

Figure 54 shows the steady time values for each of the controls. The only differences found to be significant were for the longitudinal and lateral controls in fore-aft flight. There is a smaller percentage of steady time for these controls with the wing and tail on. This confirms the previous results, indicating greater work load with the wing and tail on.

Power Spectral Density

Configuration differences appear to be restricted to longitudinal control behavior and are quite similar regardless of air-taxi direction. Forward and rearward trials indicate slightly more of the random low-frequency control inputs characteristic of the

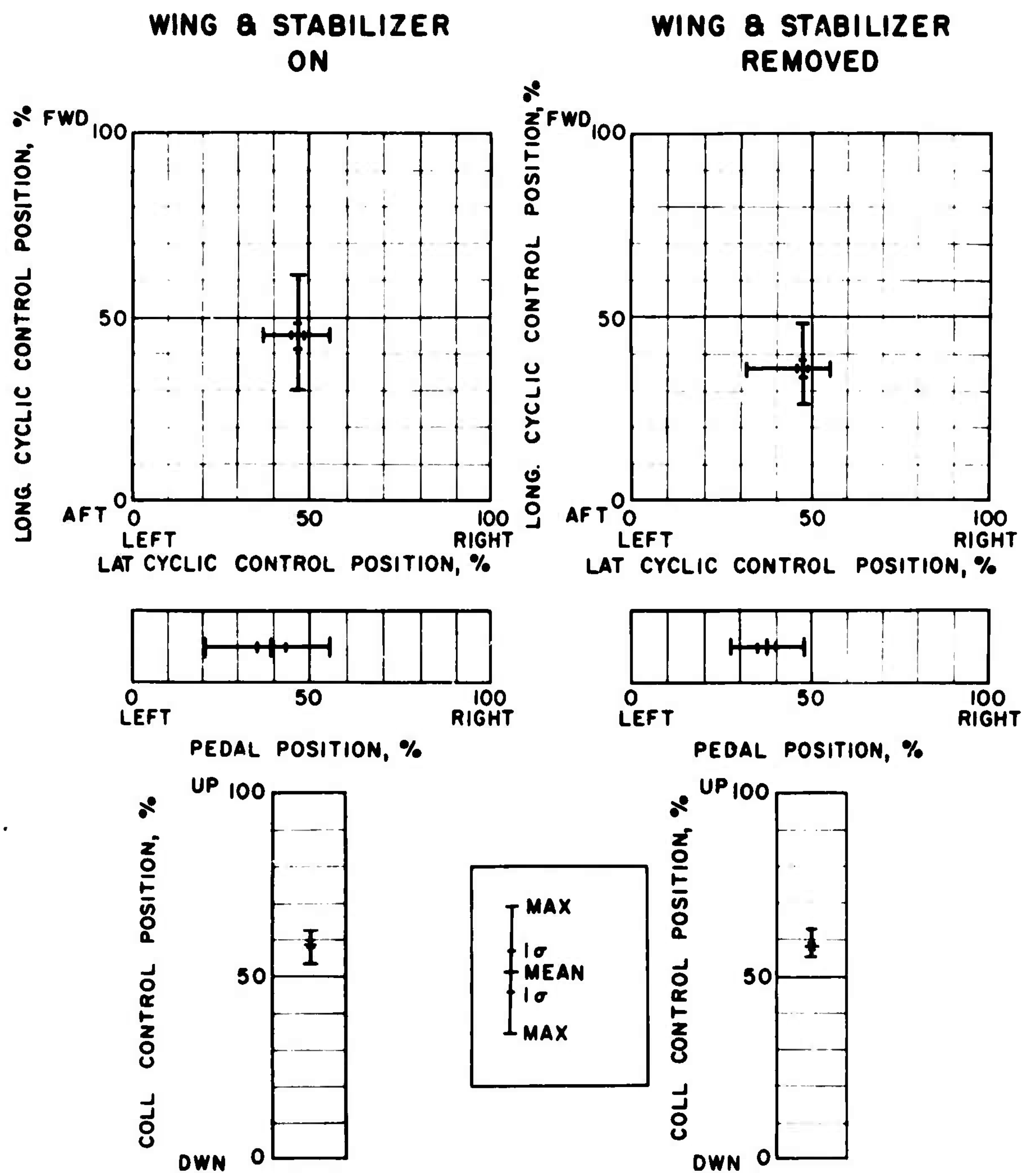


FIGURE 48. LEFT-SIDEWARD AIR TAXI — CONTROL POSITIONS

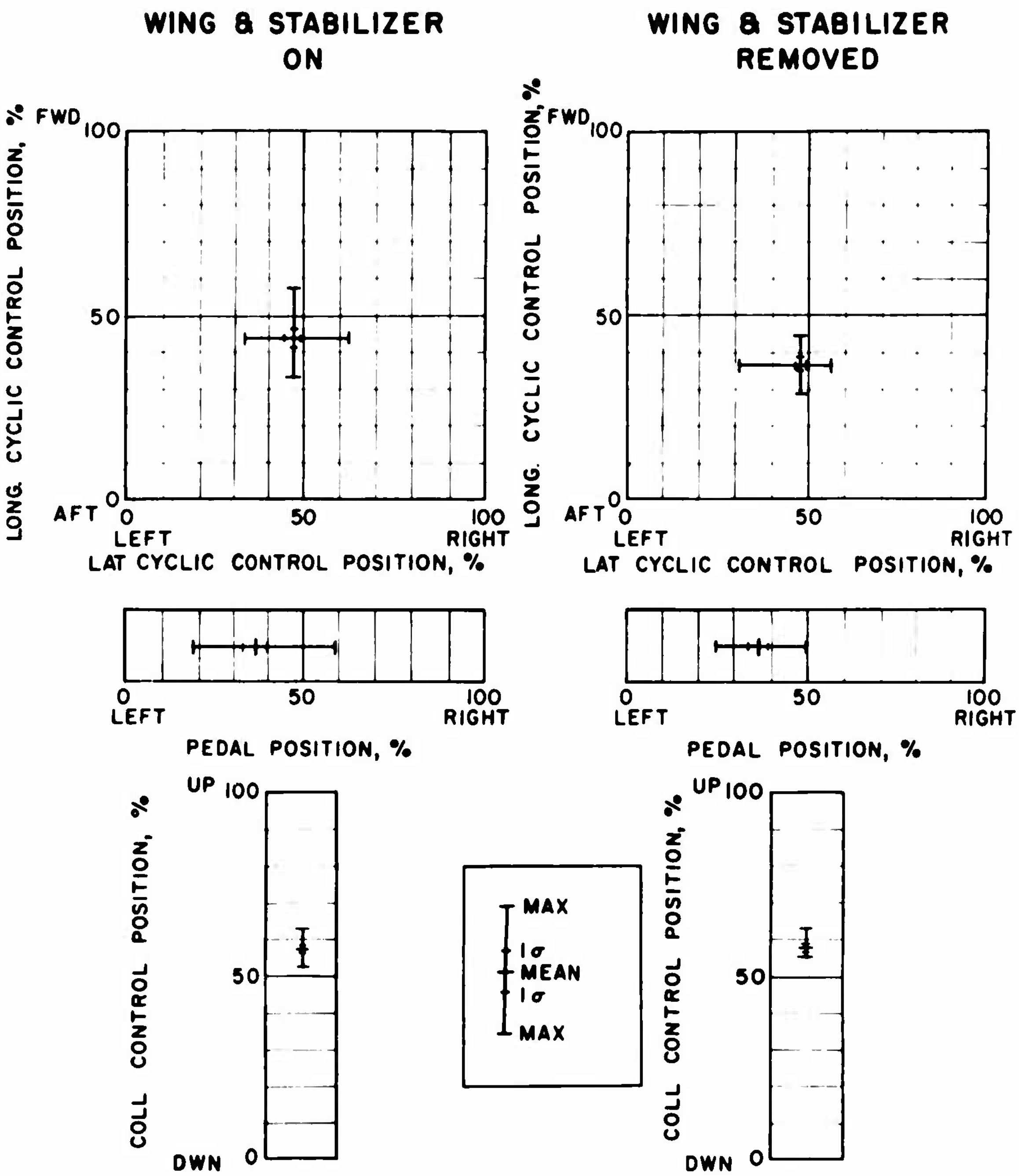


FIGURE 49. RIGHT-SIDEWARD AIR TAXI — CONTROL POSITIONS

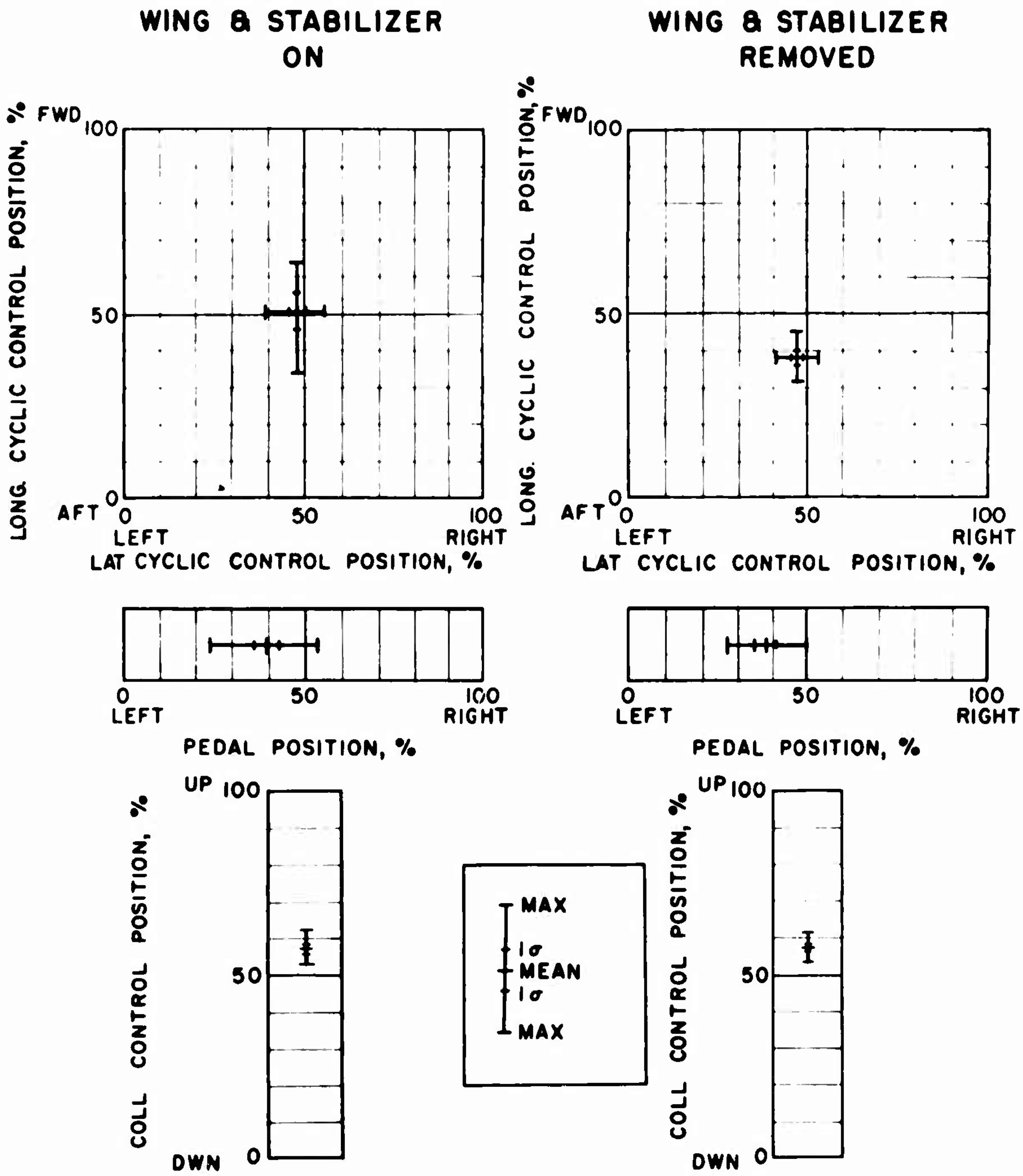


FIGURE 50. FORWARD AIR TAXI — CONTROL POSITIONS

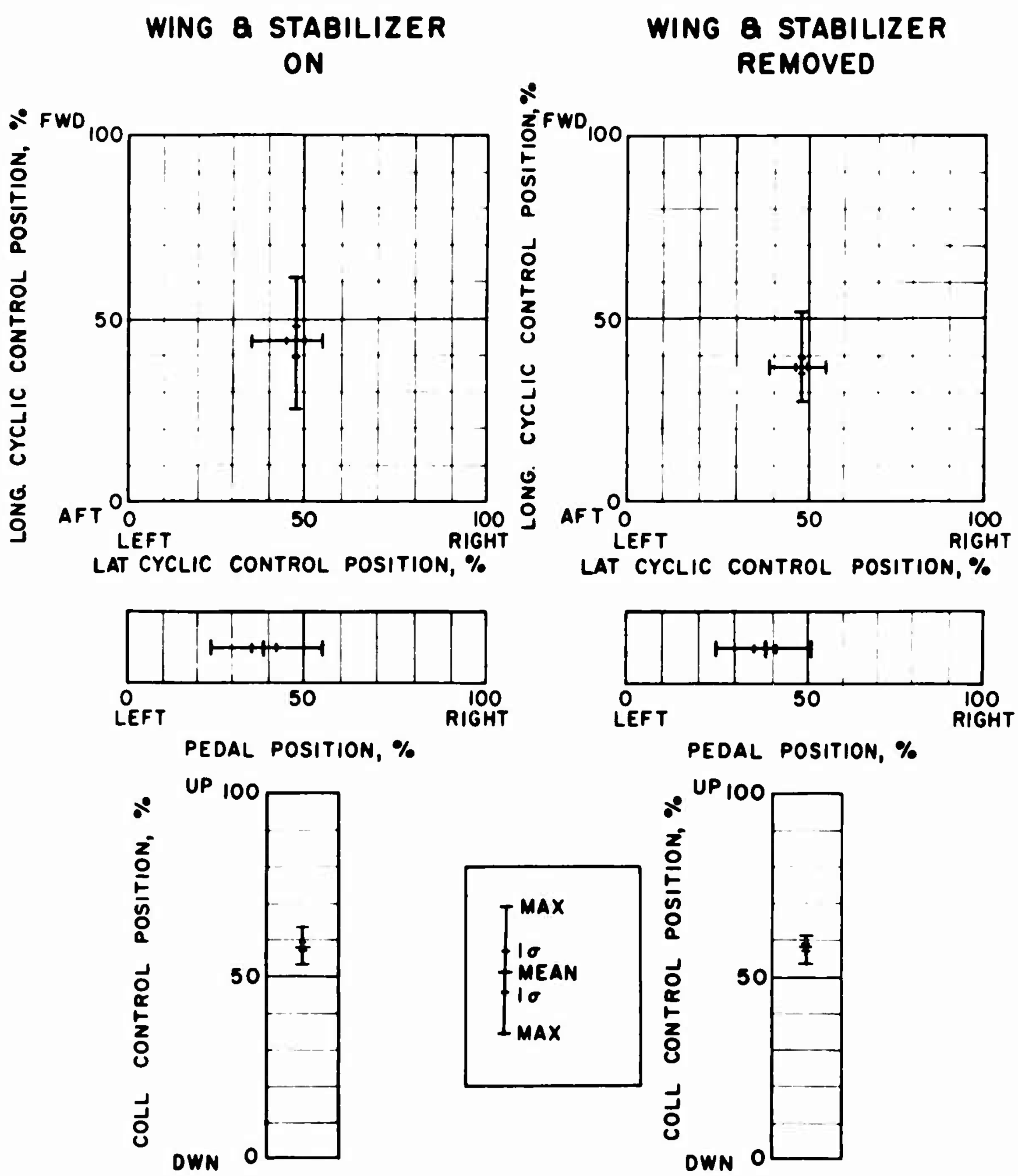


FIGURE 51. REARWARD AIR TAXI — CONTROL POSITIONS

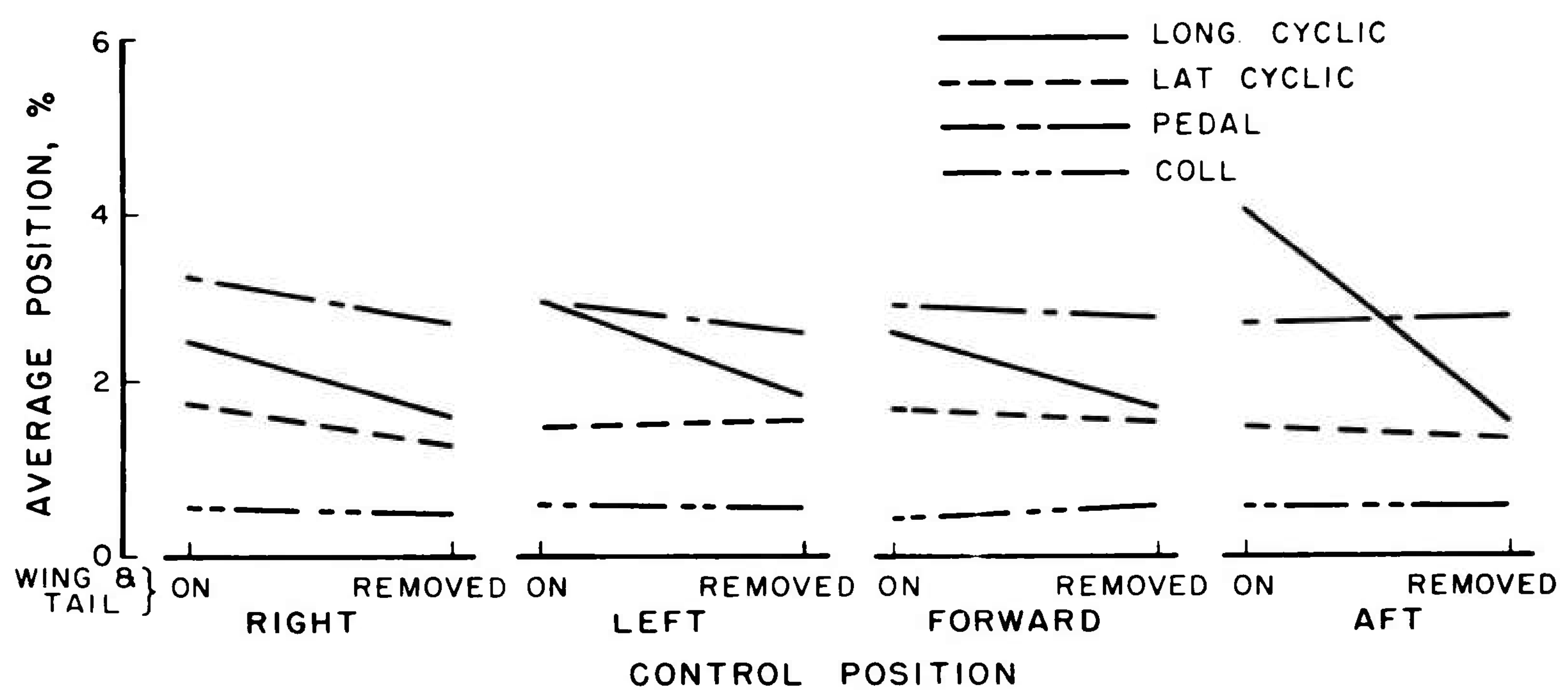


FIGURE 52. AIR TAXI — CONTROL AMPLITUDE

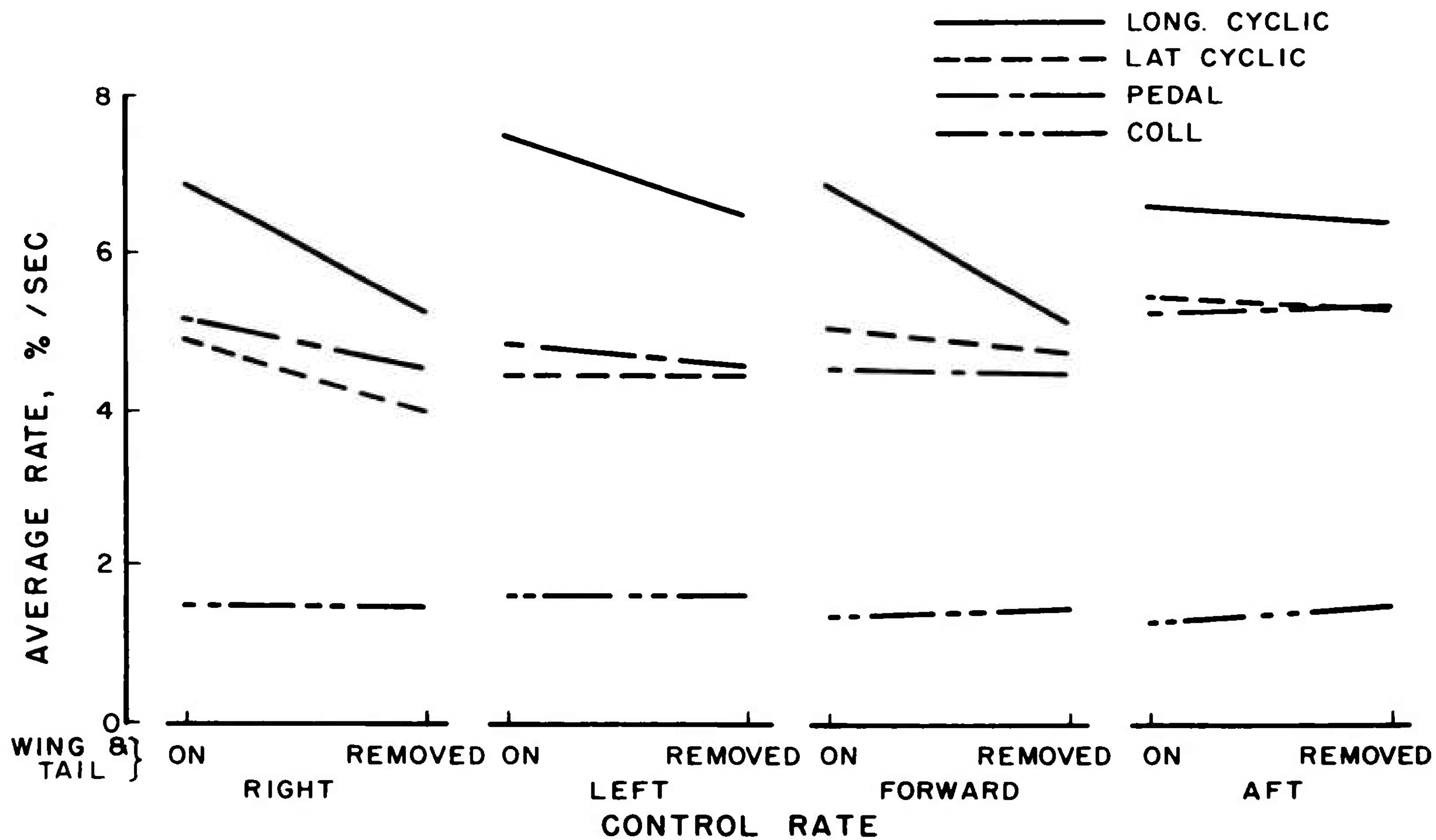


FIGURE 53. AIR TAXI — CONTROL RATE

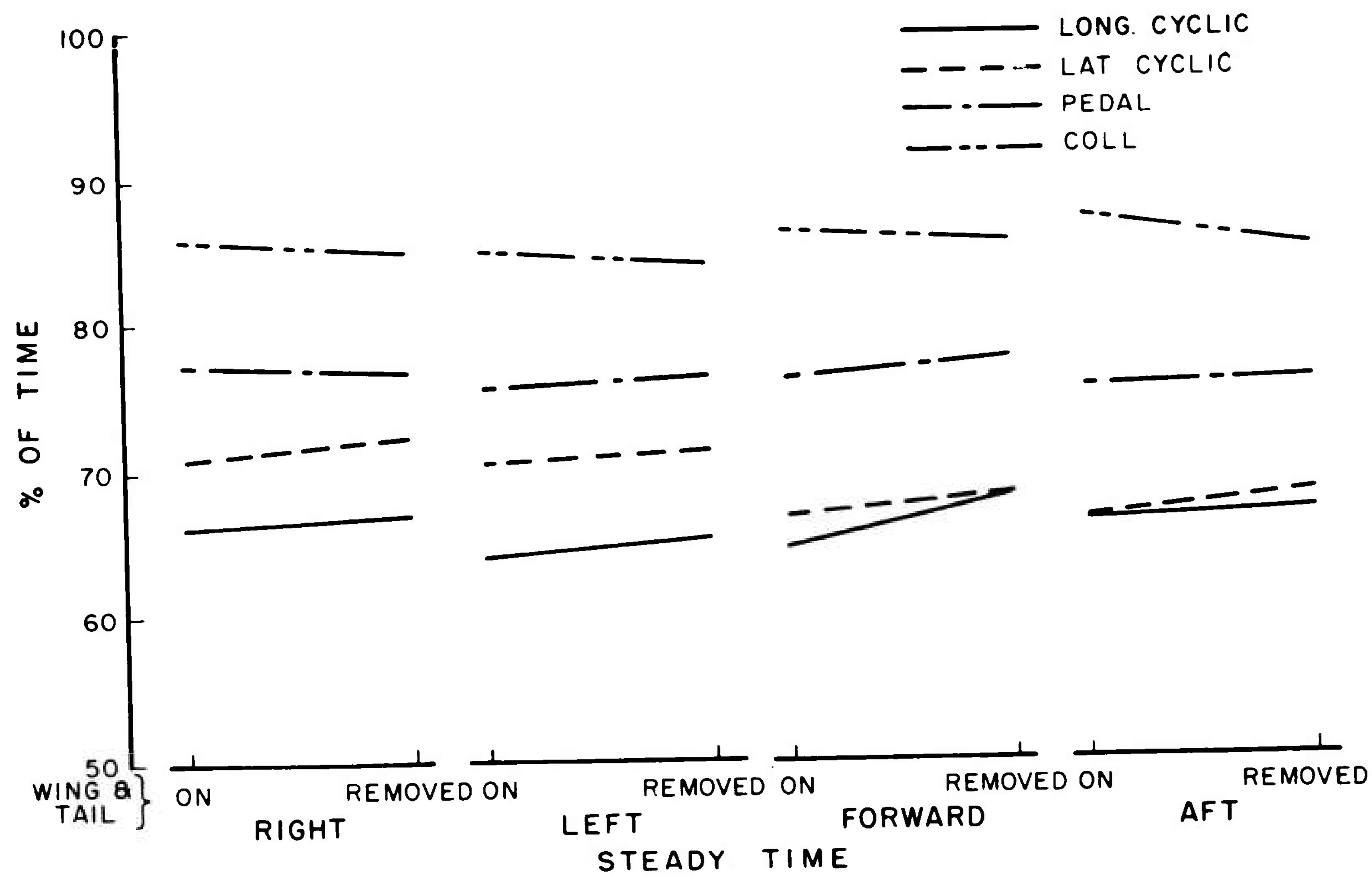


FIGURE 54. AIR TAXI — CONTROL STEADY TIME

effects of unsteady forces acting on the horizontal stabilizer in the wing-and-tail-on configuration. With this configuration, the largest portion of power is generated below .4 cps, while the wing-and-tail-off configuration shows power densities indicating predictable inputs with the power centered at .4 cps. In sideward flight with wing and tail on, the frequencies are lower and more spread out. The wing-and-tail-off configuration shows a higher concentration of power in a narrower band at a slightly higher frequency.

The frequency measures must be considered along with the control rate and amplitude data in order to understand the whole picture of pilot control behavior. Rate and amplitude are always greater with the wing and tail on, which indicates a low-frequency random input with high amplitude and rate.

Differences due to configuration or direction are not clearly detectable in lateral cyclic, collective or pedals. Pilot individual differences and intertrial variability are evident throughout.

Pilot Opinion Data

The pilot opinion data for the air-taxi task, Figure 55, are somewhat more consistent than for the hover tasks. For both the performance and work-load ratings, Pilots 2 and 3 show a preference for the wing-and-tail-off configuration. Pilot 1, however, rated the two configurations identically. On the Cooper-Harper Rating Scale, all ratings were between 4 and 6. Pilots 2 and 3 again rated the wing-and-tail-off configuration better than the wing-and-tail-on configuration; Pilot 1 gave the same value to the two configurations.

Evaluation

The measures of positional accuracy were found to be sensitive to configuration difference and generally indicate more accurate performance with the wing and tail off. Configuration differences were also evident in the work-load data. Both control activity and aircraft attitude activity measures showed increased steadiness with the wing and horizontal stabilizer removed. The power spectral density data revealed differences in longitudinal control behavior. Pilot opinion data were somewhat more consistent, with 2 out of 3 pilots favoring the wing-and-tail-off configuration. The overall picture indicates that the effects of wing and horizontal stabilizer in air taxi are poorer precision, increased work load, and less favorable opinion.

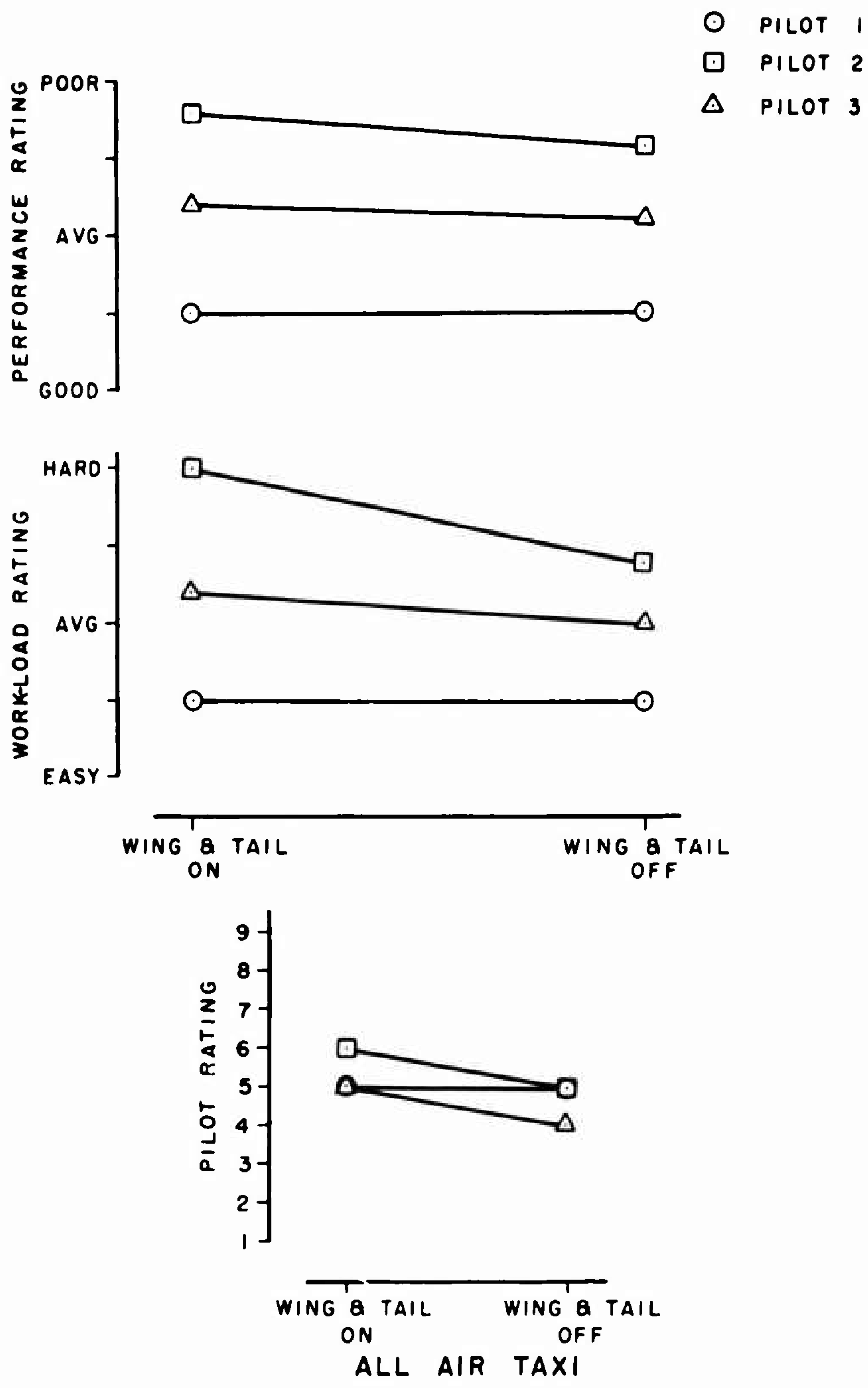


FIGURE 55. AIR TAXI — PILOT OPINION

ACCELERATION MANEUVER

Initially, the acceleration maneuvers were analyzed in total; that is, error measures were averaged from 0 to 120 knots. After examination of these data, it was felt that this method might obscure some interesting speed-related differences between configurations. The data were reanalyzed by breaking each maneuver into a low-speed portion (0-60 knots) and a high-speed portion (60-120 knots). All data are presented this way except the pilot opinion data, which were taken after each trial and represent a rating of that acceleration trial as a whole.

Objective Measures

Figure 56 shows the effect of speed and configuration on measures of heading error and altitude error. Both differed significantly with configuration and speed (Table X). Altitude error was always greater with the wing and tail off. This is believed to be mainly due to the reluctance of the pilots to continue the acceleration at low level with the reduced stick stability and unfamiliar responses of the wing-and-tail-off configuration. Heading, on the other hand, was better at low speed and in the wing-and-tail-off configuration.

Work-Load Measures

Attitude Activity

The standard deviations of aircraft attitude rates are shown in Figure 57. The analyses of variance indicate that none of the differences due to configuration reach significance. Pitch rate and yaw rate, however, do differ significantly with speed. The pitch difference with speed is mainly apparent for the wing-and-tail-on configuration, where the unsteady pitching moments due to rotor downwash give way to pitch stability as the airspeed increases.

Control Positions

Figures 58 and 59 show the means, standard deviations, and maximum inputs for longitudinal cyclic, lateral cyclic, collective, and pedals for the 0-to-60-knot and 60-to-120 knot portions of the acceleration tasks.

In the low-speed portion, the most outstanding configuration difference is seen in the longitudinal cyclic control position plots. The wings-and-stabilizer-on configuration shows a larger than 20% forward shift in trim stick position. In addition, the standard deviation and peak values greatly exceed the values observed with

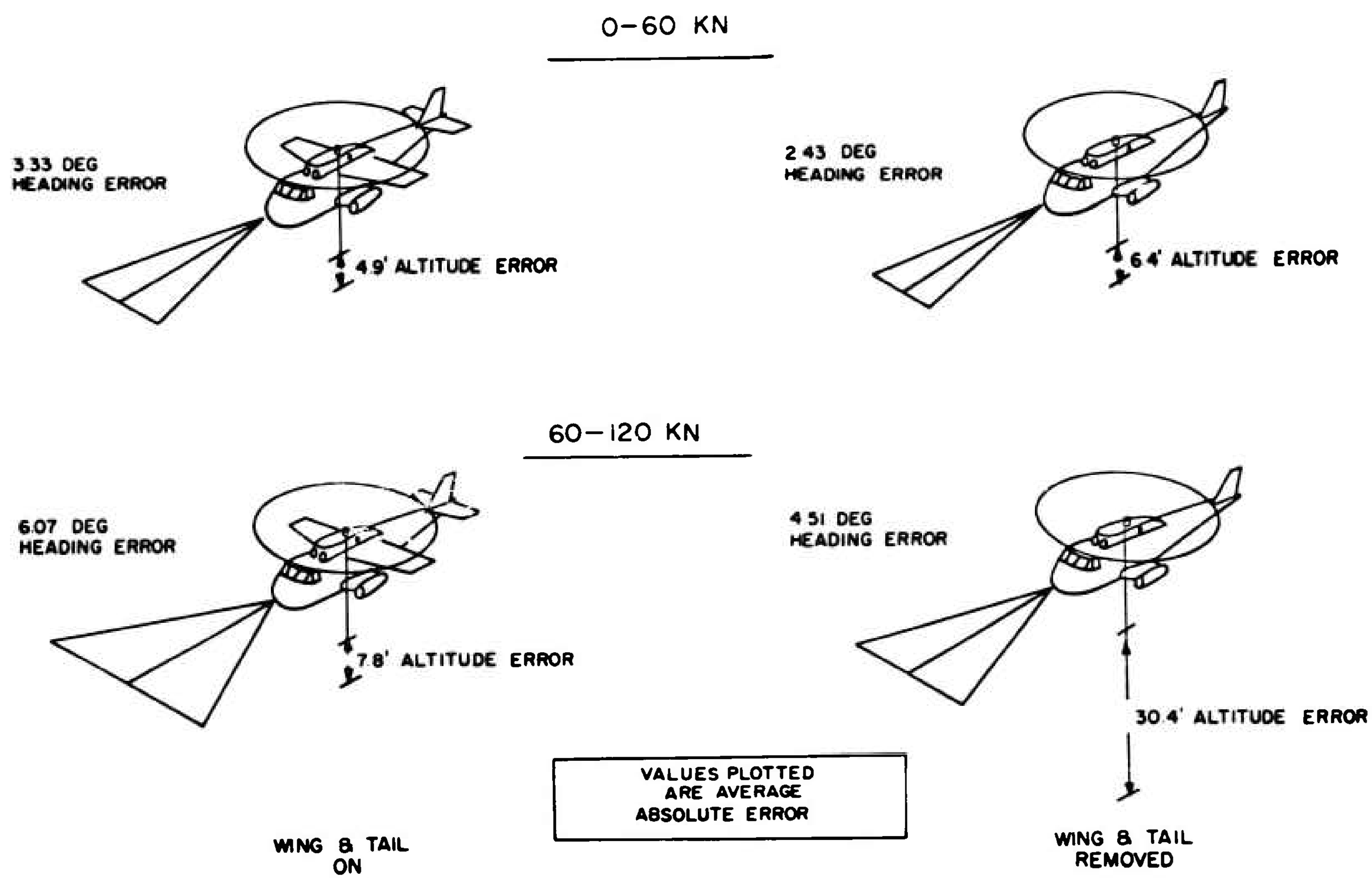


FIGURE 56. ACCELERATION — AVERAGE ABSOLUTE ERROR

TABLE X. ACCELERATIONS — ANALYSES OF VARIANCE RESULTS

PARAMETERS	Configuration A	Low - High Speed B	Pilots C	A x B	A x C	B x C	A x B x C
PHOTO PANEL DATA							
Altitude							
Average Error	X	X	X	X	N.S.	N.S.	N.S.
TAPE DATA							
Roll Rate Standard Deviation	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Pitch Rate Standard Deviation	N.S.	X	X	X	N.S.	X	X
Yaw Rate Standard Deviation	N.S.	X	N.S.	N.S.	N.S.	N.S.	N.S.
Yaw Average Error	X	X	X	N.S.	X	N.S.	X
Longitudinal Cyclic							
Average Rate	X	X	X	X	N.S.	X	N.S.
Average Position	X	X	N.S.	X	N.S.	X	X
Lateral Cyclic							
Average Rate	X	X	X	N.S.	X	X	N.S.
Average Position	N.S.	X	X	N.S.	X	X	N.S.
Collective							
Average Rate	X	X	X	N.S.	X	N.S.	N.S.
Average Position	X	X	N.S.	N.S.	N.S.	X	N.S.
Pedals							
Average Rate	N.S.	X	X	N.S.	X	X	N.S.
Average Position	N.S.	X	N.S.	X	N.S.	N.S.	X

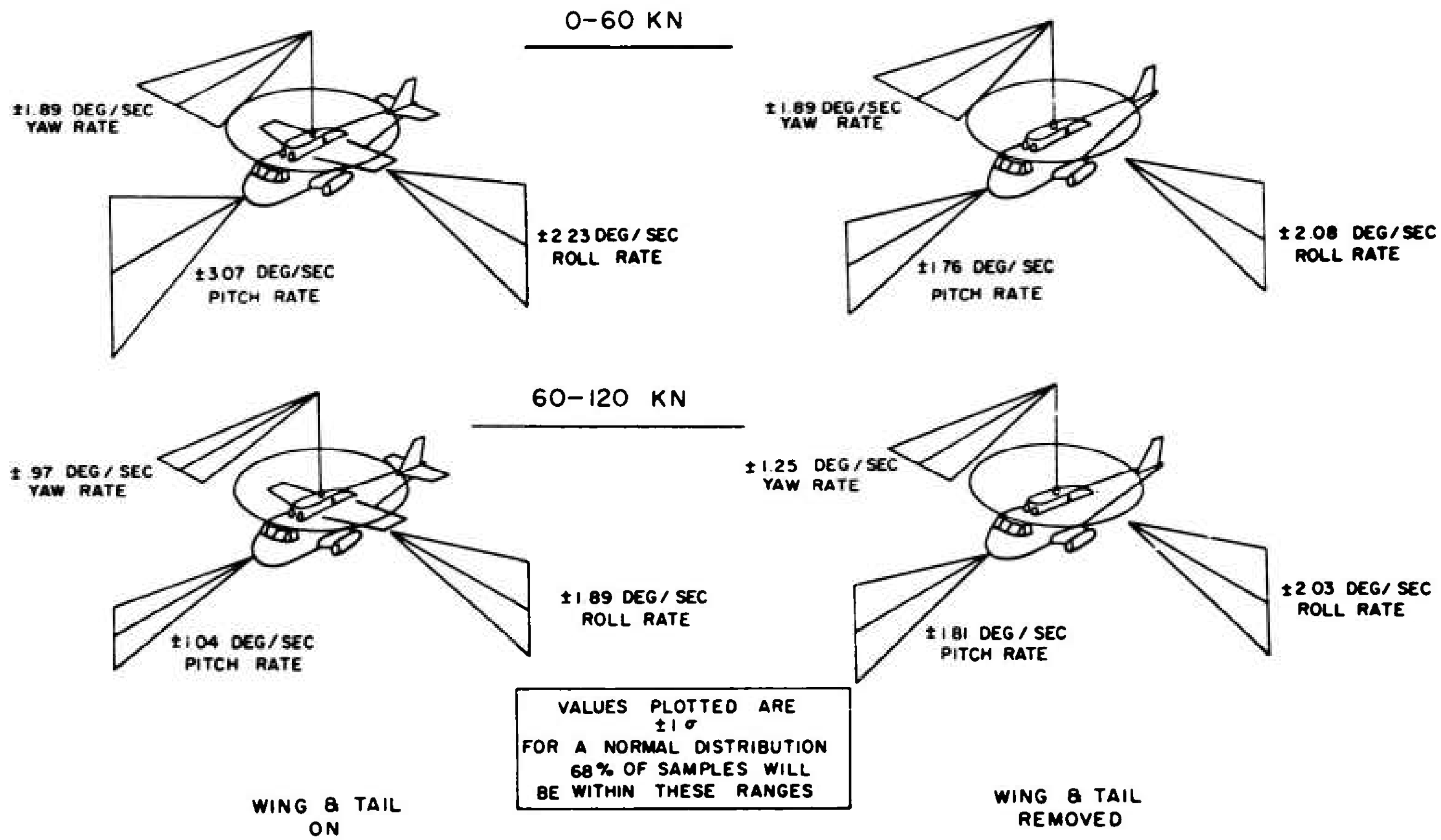


FIGURE 57. ACCELERATION — ATTITUDE RATES

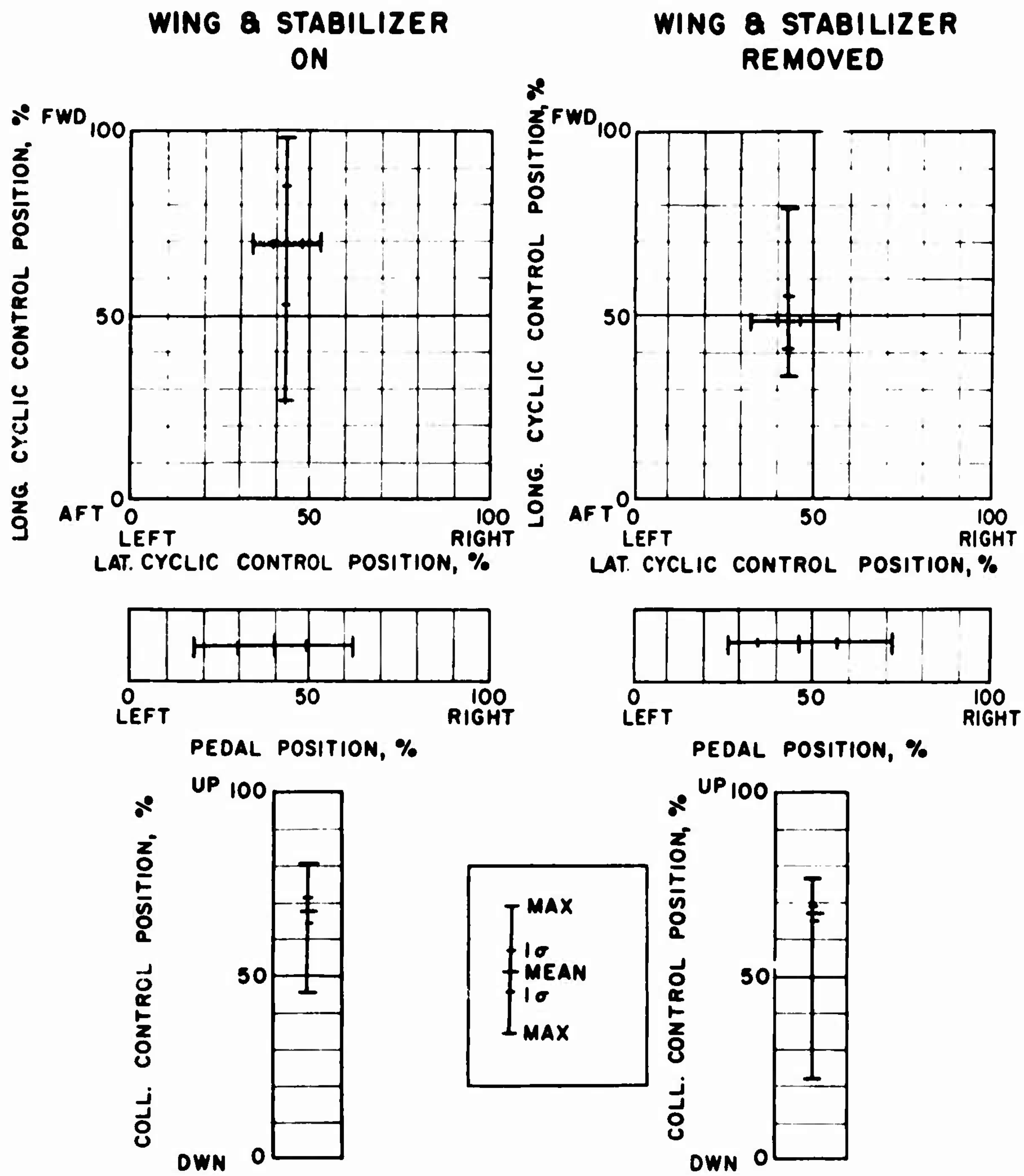


FIGURE 58. ACCELERATION — 0 - 60 KN, CONTROL POSITIONS

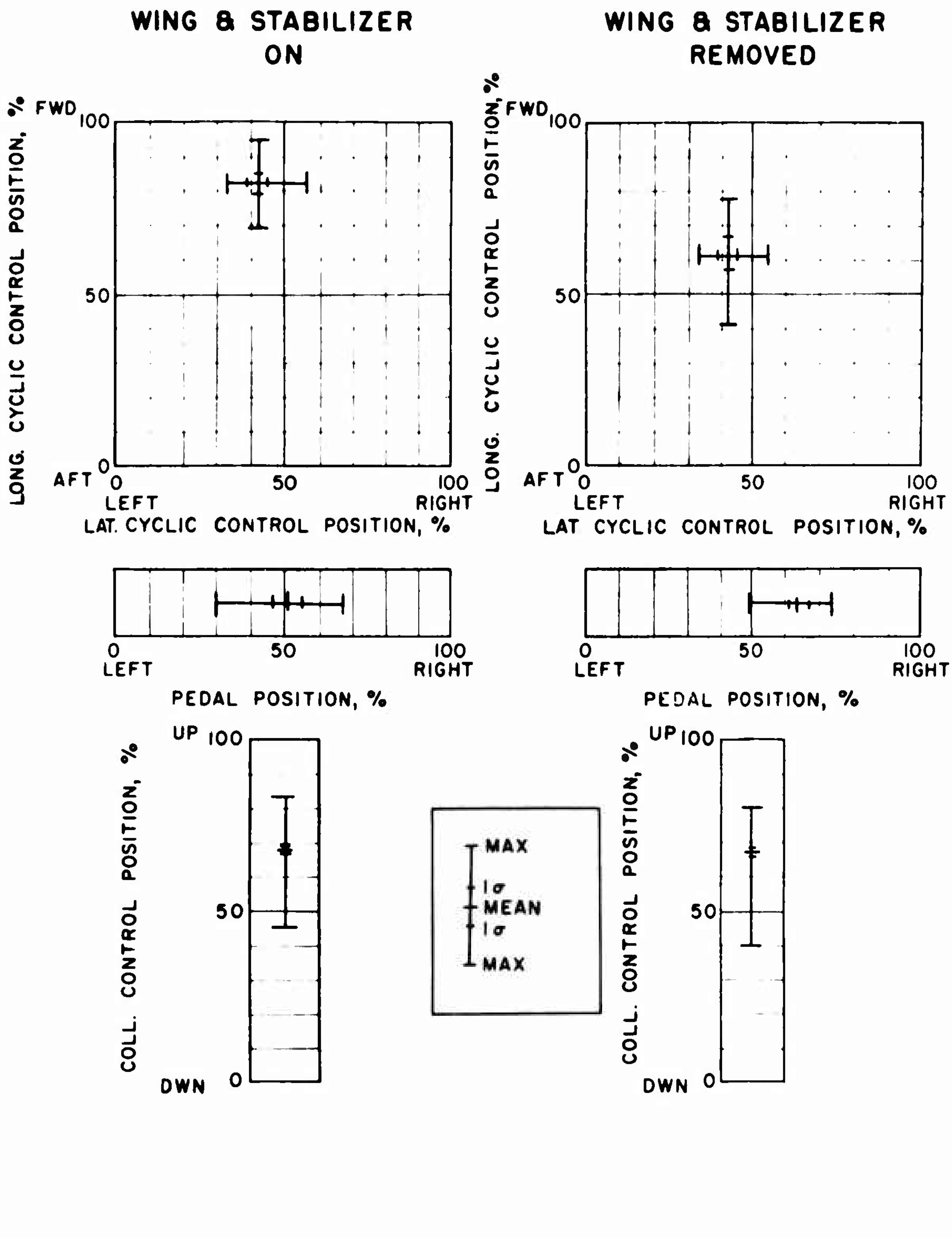


FIGURE 59. ACCELERATION — 60 - 120 KN, CONTROL POSITIONS

wing and stabilizer removed. In the high-speed portion of the acceleration, the longitudinal trim shift is still evident but not the standard deviation; peak values are greater for the wing-and-tail-off configuration, thus indicating a reduced pitch stability at higher speeds.

Lateral cyclic is not sensitive to changes in configuration, but the pedal trim position is shifted to the right in the wing-and-tail-off cases for both the high- and low-speed portions. This is due to the increased antitorque requirement caused by the increased main rotor thrust needed to offset the negative wing lift in acceleration. The separation of mean pedal positions is greater for the high-speed portion than for the low-speed part. Collective pitch requirements were slightly higher for the winged configuration.

Control Activity

Figure 60, a summary of the measured control rates and amplitudes, shows that the rates of all controls diminished in the wing-and-tail-off configuration for both the low- and high-speed portions. This effect was significant for all controls except pedals.

All control rates were higher for the 60-120-knot portions, and the analyses of variance showed all of these effects to be significant.

The interaction between speed and configuration is clearly shown by the longitudinal control amplitude measures. The wing-and-tail-on vs. wing-and-tail-off comparison for the 0-60-knot portion shows a much larger control amplitude for the on condition. This is caused by the unsteady pitching moments resulting from the rotor downwash flow over the horizontal stabilizer as the aircraft accelerates. The beneficial effect of the wing and stabilizer can be seen in the high-speed portion where the longitudinal amplitude is greater with the wing off. In this case the pilot is required to provide the longitudinal stability which the horizontal tail normally supplies.

Power Spectral Density

The power spectral density calculations for the split low-speed/high-speed data revealed consistent differences between the two portions of the maneuver for longitudinal cyclic motions. The low-speed portions for both configurations showed a high proportion of power at the low frequencies. This, combined with the amplitude and rate data, indicates that the pilot made large steady inputs at low frequency to accelerate from hover. At higher speeds the input frequency increased as did the rate, while amplitude diminished.

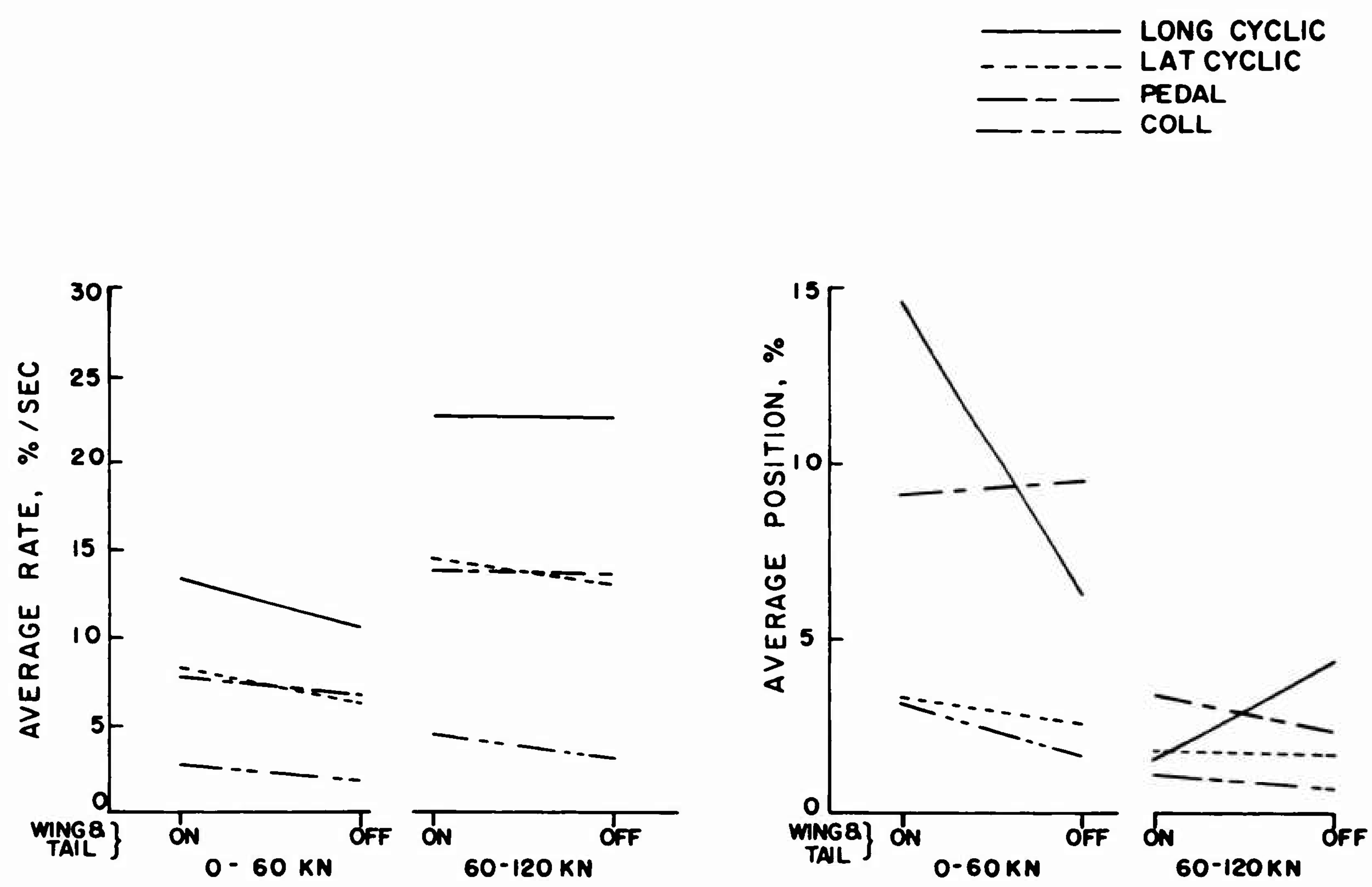


FIGURE 60. ACCELERATION — CONTROL RATE AND AMPLITUDE

This is indicative of the small pitch corrections necessary as speed builds up.

Laterally, the pilot individual differences and intertrial variability obscure any difference between configuration and speed. In addition, the short duration of each run reduces the reliability of the power spectral density calculations.

Pilot Opinion Data

As shown in Figure 61, opinion differed as to the effects of configuration. Performance ratings are grouped tightly around the average value, with Pilot 1 showing no change and Pilot 2 and 3 rating their performance slightly better with wing and tail off. Work-load ratings again showed Pilots 2 and 3 slightly favoring the wing-and-tail-off configuration and Pilot 1 showing a considerable preference for the other.

The Cooper-Harper ratings revealed a different pattern of responses. Pilot 1 rated both configurations A5, Pilot 2 rated them A4, and Pilot 3 rated wing and tail on A5 and wing and tail off A6.

Evaluation

Perhaps the most important result of the acceleration tasks was the difference in ability to hold constant altitude. The reduced stability and unfamiliar response of the aircraft with wing and tail off resulted in rather large altitude errors at higher speeds.

The control data reveal the interaction of configuration and speed. The control amplitudes are greatest for wing and tail on at low speed, where rotor wash is striking the horizontal tail, and for the wing-and-tail-off configuration at high speed, where pitch stability is reduced.

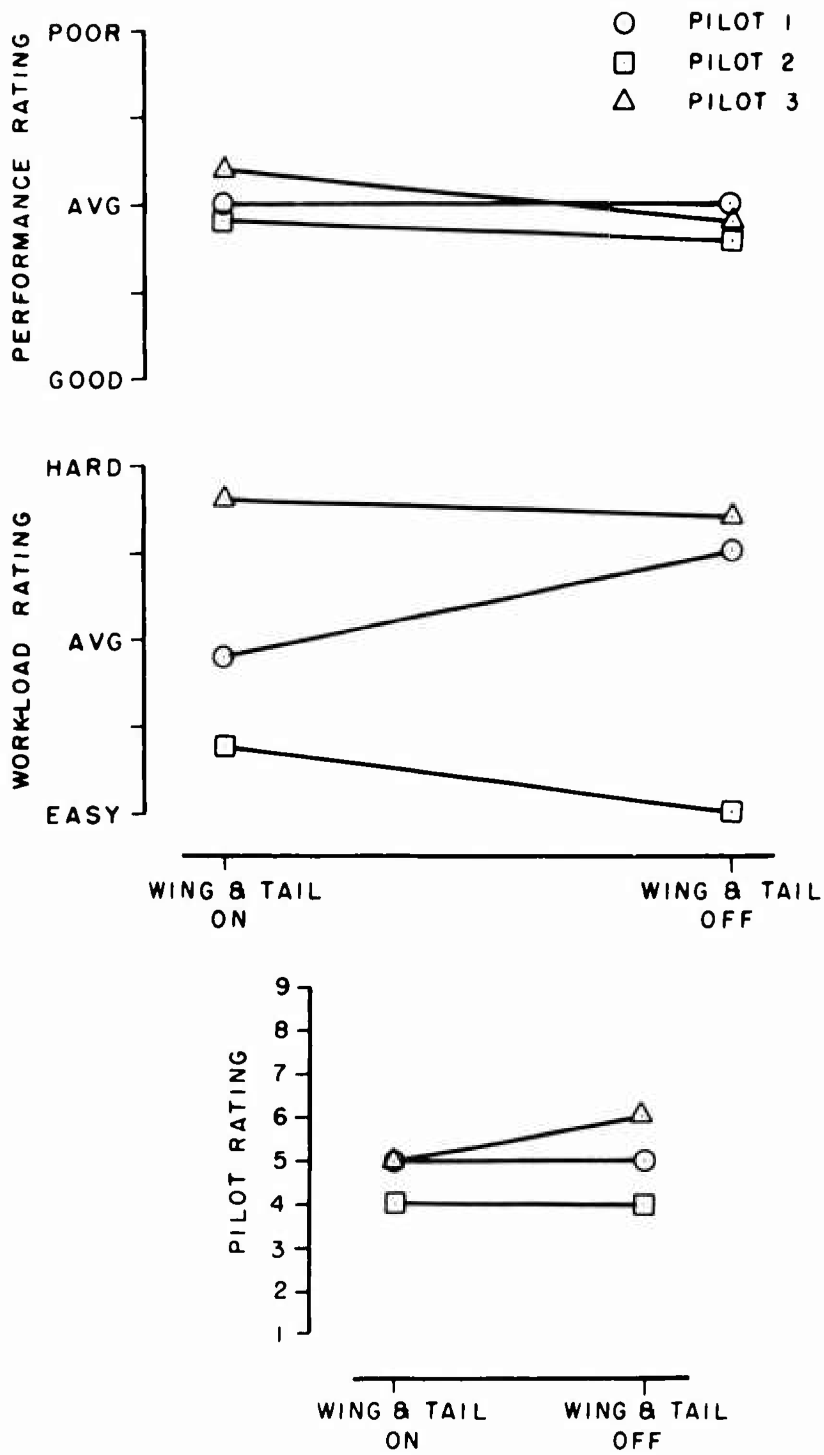


FIGURE 61. ACCELERATION — PILOT OPINION

DECELERATION MANEUVER

The deceleration trials, like the accelerations, were broken into a high-speed portion (120-60 knots) and a low-speed portion (60-0 knots) in order to clarify the effects of the compound configuration on performance and work load.

Objective Measures

Figure 62 illustrates the heading and altitude errors measured during the deceleration trials. Heading errors were found to differ significantly with speed but not with configuration. The errors were greater in the low-speed portion of the tasks, Table XI. Altitude precision was significantly worse with the wing and tail off, which again seems to be caused by the reluctance of the pilots to operate the aircraft near the ground without the stabilizing effect of wing and tail. This is confirmed by the fact that the error is greater in the high-speed portion.

Work-Load Measures

Attitude Activity

As shown in Figure 63, pitch and yaw rates differ significantly with configuration. Pitch rate increases from high to low speed with the wing and tail on and decreases from high to low speed with the wing and tail off. This is indicative of the beneficial effects of the compound configuration at high speed and its negative effects at low speed. Yaw rate increases at low speed with both configurations.

Control Position

Mean positions, standard deviations and peak inputs are shown in Figures 64 and 65 for the high- and low-speed portions of the deceleration. Figure 64 is the first plot which shows the disappearance of the characteristic longitudinal trim difference between configurations. In fact, there is a slight rearward shift for the wing-and-stabilizer-on configuration which apparently offsets the nose-down pitching moment due to an up load on the horizontal stabilizer in the approach to hover. The situation changes in the low-speed portion as shown in Figure 65. The 10% difference in longitudinal stick position occurs again as the pilot moves the stick forward to compensate for horizontal stabilizer download at low speed. In addition, the expected expansion of the longitudinal stick envelope and standard deviation boundary due to the unsteady rotor wash effects on the horizontal stabilizer are seen in this figure.

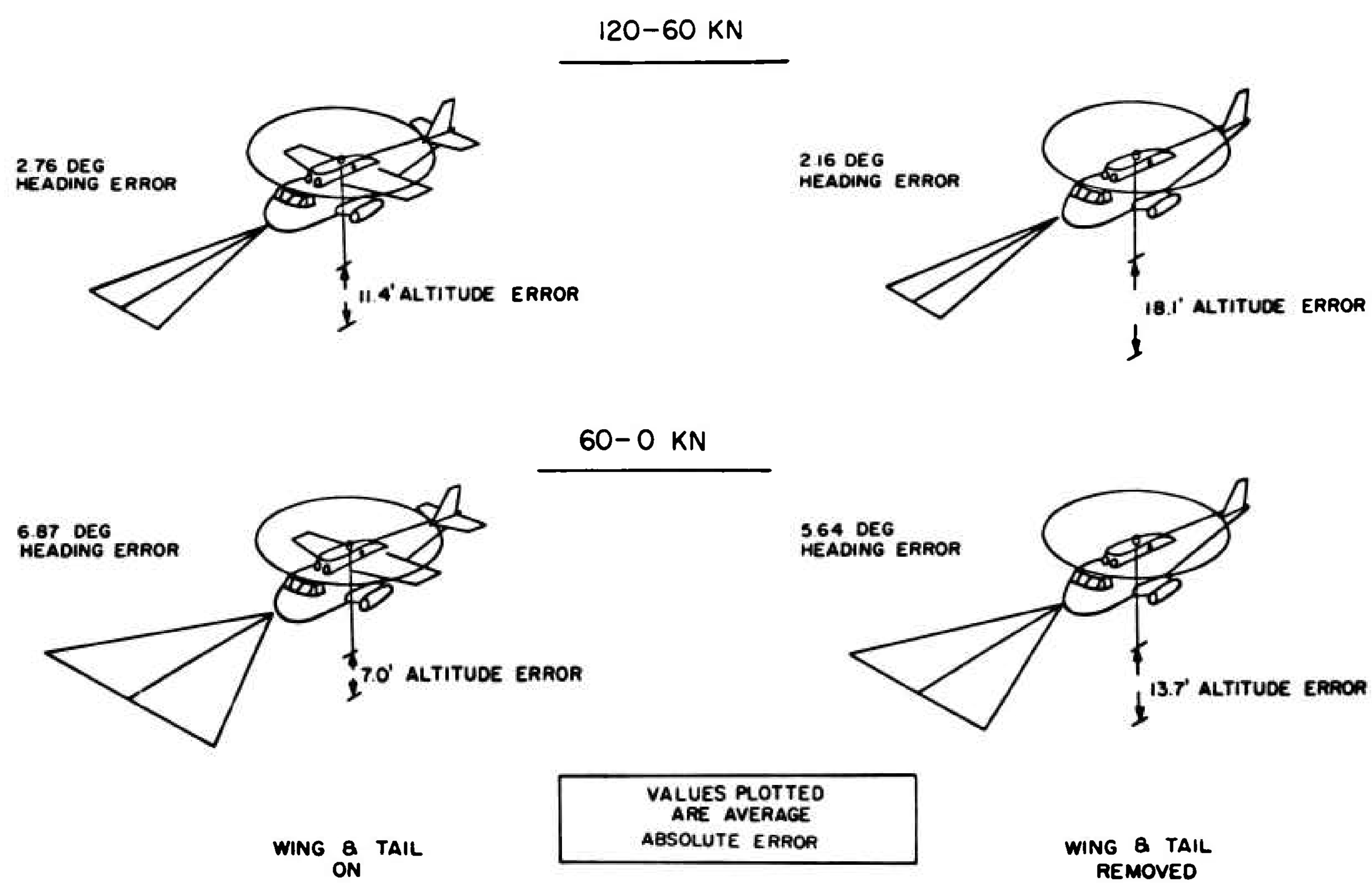


FIGURE 62. DECELERATION — AVERAGE ABSOLUTE ERROR

TABLE XI. DECELERATIONS — ANALYSES OF VARIANCE RESULTS

PARAMETER	Configuration A	High vs. Low Speed B	Pilots C	A x B	A x C	B x C	A x B x C
PHOTO PANEL DATA							
Altitude							
Average Error	X	X	N.S.	N.S.	X	X	X
TAPE DATA							
Roll Rate Standard Deviation	N.S.	N.S.	X	N.S.	X	N.S.	N.S.
Pitch Rate Standard Deviation	X	N.S.	X	X	X	N.S.	N.S.
Yaw Rate Standard Deviation	X	X	X	X	X	N.S.	N.S.
Yaw Average Error	N.S.	X	X	N.S.	N.S.	X	N.S.
Longitudinal Cyclic							
Average Rate	X	X	X	N.S.	X	N.S.	N.S.
Average Position	X	X	X	X	N.S.	N.S.	N.S.
Lateral Cyclic							
Average Rate	X	X	X	N.S.	X	X	N.S.
Average Position	X	X	N.S.	X	X	N.S.	N.S.
Collective							
Average Rate	X	X	X	N.S.	X	N.S.	N.S.
Average Position	X	X	X	N.S.	N.S.	N.S.	N.S.
Pedals							
Average Rate	X	X	X	N.S.	N.S.	X	N.S.
Average Position	X	X	X	X	N.S.	N.S.	N.S.

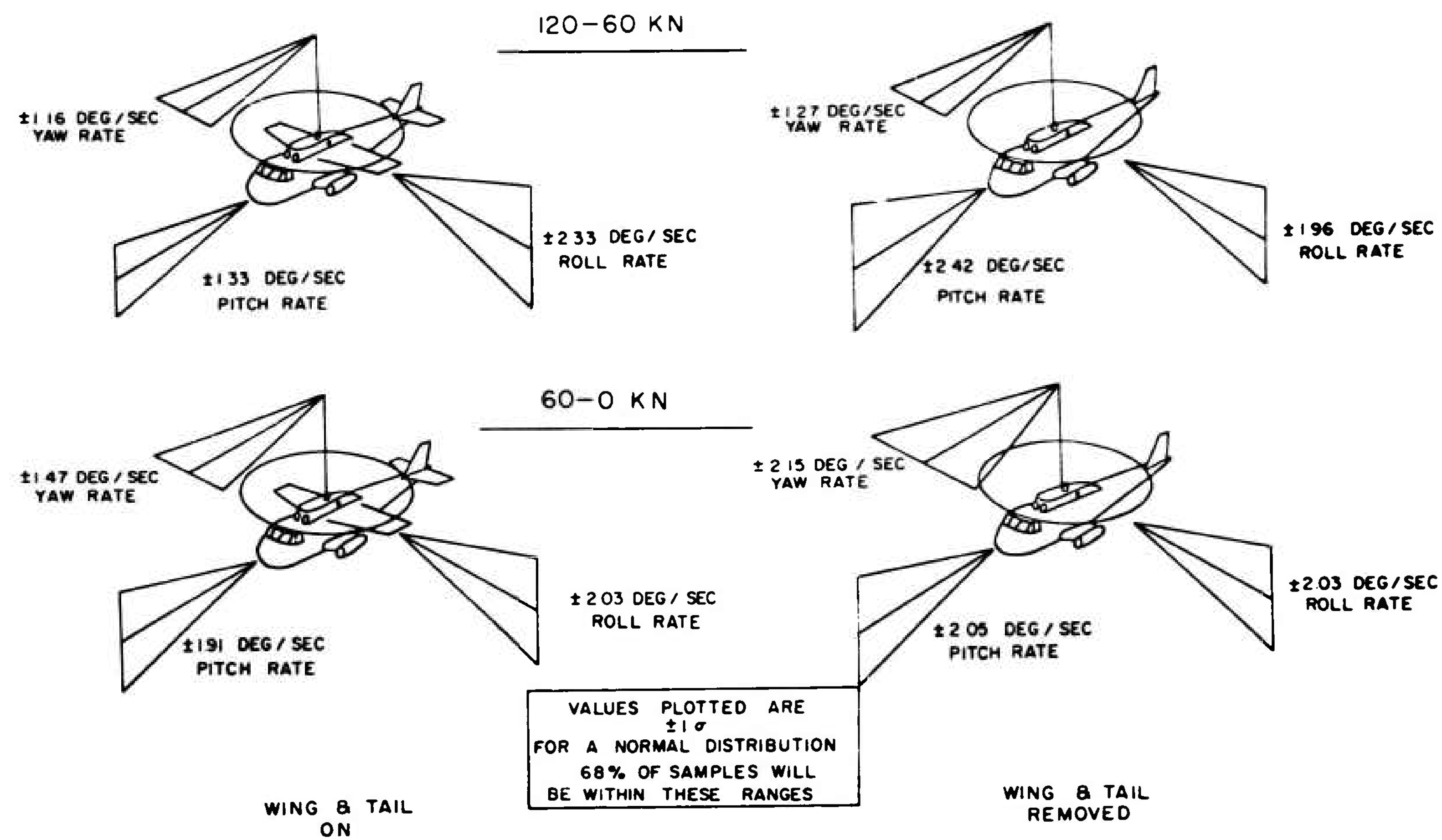


FIGURE 63. DECELERATION — ATTITUDE RATES

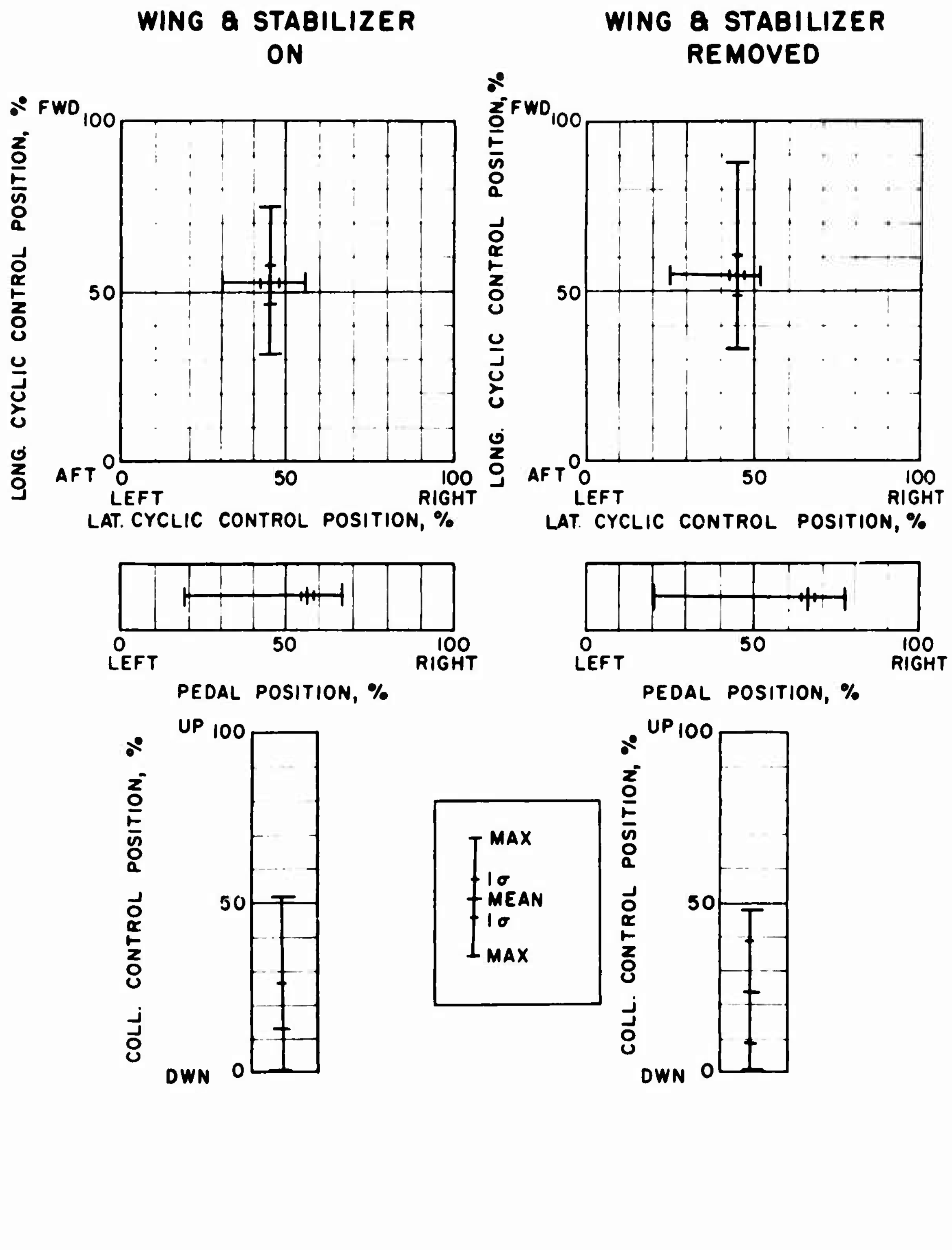


FIGURE 64. DECELERATION — 120 - 60 KN, CONTROL POSITIONS

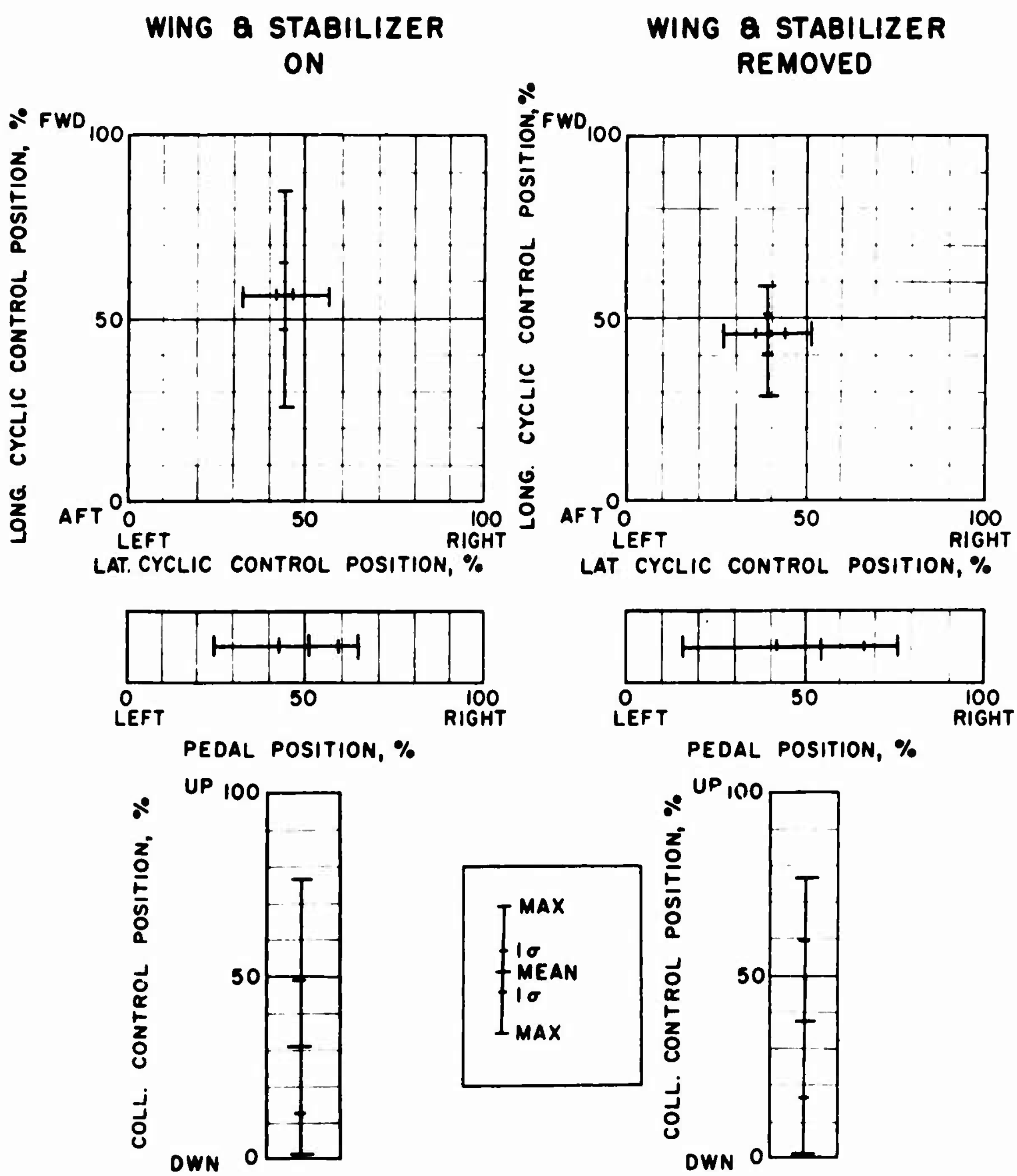


FIGURE 65. DECELERATION — 60 - 0 KN, CONTROL POSITIONS

The lateral cyclic measures do not appear to be sensitive to configuration for either the high- or low-speed portions. The collective requirements are higher for the wing-and-tail-off configuration because of the necessity of generating the decelerating force with the rotor. The compound configuration makes use of the wing to produce lift and drag as the aircraft decelerates.

Control Activity

Figure 66 shows that control rate and amplitude measures for deceleration varied significantly with configuration and speed.

It is seen that all control rates increased as speed decreased and also that all rates, except for collective, were higher in the wing-and-tail-off configuration. This would indicate a higher work load for deceleration with the wing-and-tail-off configuration regardless of speed. Most of the other tasks have indicated a steadying of control with the wing and tail off at low speeds. The cause here is probably the pilots' concern as they attempt to decelerate at low altitude an aircraft with somewhat unfamiliar pitch response characteristics.

The control position data indicate that control amplitudes are generally greater in the low-speed portion. The collective amplitude was greater with the wing and tail off for both the low- and high-speed portions. This again reflects the need for generating a larger decelerating force with the rotor when the wing is removed. The changes of longitudinal and lateral cyclic and pedals with configuration were quite small in the high-speed portion. However, in the low-speed part, longitudinal stick amplitude changed markedly with configuration, as previously indicated by the large standard deviation envelope shown in Figure 65. This pattern is indicative of large, slow motions of the longitudinal control probably resulting from trim changes which occur when the rotor downwash impinges on the horizontal stabilizer.

Power Spectral Density

In deceleration, both longitudinal and lateral cyclic controls show different power spectral density profiles with configuration and speed. In the high-speed portion with the wing and tail on, frequency, amplitude, and rate are low, indicating a low work-load situation. Below 60 knots the data begin to show the large-amplitude control motion typical of the low-speed behavior of this configuration. With wing and tail removed, the pilot flies the high-speed portion with slightly higher frequency, high rate inputs of an average amplitude

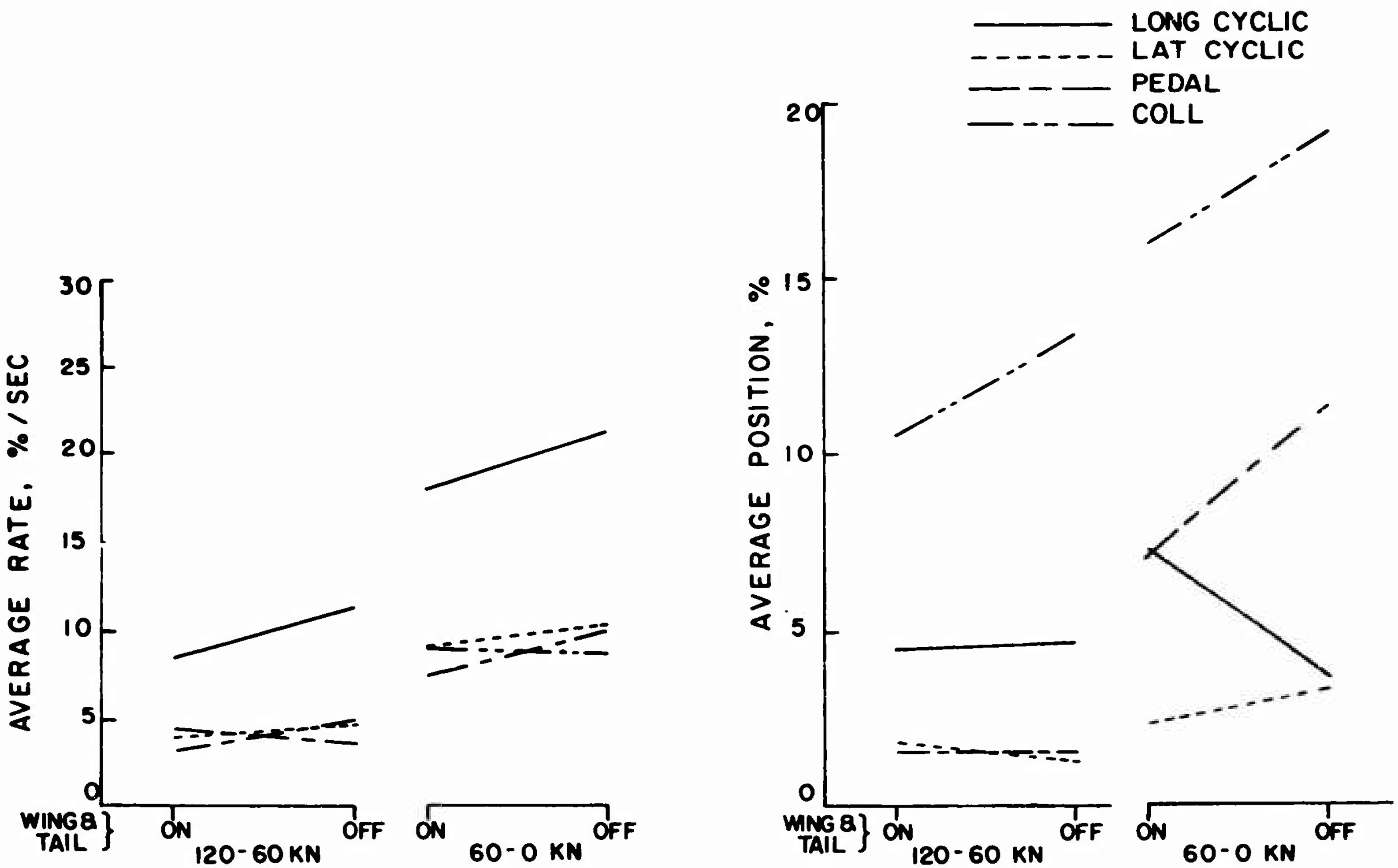


FIGURE 66. DECELERATION — CONTROL RATES AND AMPLITUDES

comparable to those seen in the high-speed regime for the other configuration. As the speed drops below 60 knots, the input frequency increases and the rate remains high, but the amplitude falls considerably below that used for the wing-and-tail-on configuration, indicating a less-demanding control task.

Laterally, the configurations do not differ greatly in their power spectral density profiles at low speed. At high speed, however, lateral control of the wing-and-tail-off configuration shows relatively more power above .4 cps than does the winged configuration. This effect is not as clearly defined as the longitudinal differences.

Pilot and intertrial differences again account for nearly as much difference as was produced by the configuration changes. Again these data suffer from the short duration of the maneuver.

Pilot Opinion Data

As shown in Figure 67, Pilots 1 and 2 believed that their performance was poorer and Pilot 3 that his performance was better with the wing and tail off. All three agreed in their work-load ratings that the wing-and-tail-off configuration was more difficult to fly. The Cooper-Harper rating data show all three pilots rating the wing-and-tail-on configuration A4. Pilots 1 and 3 rated the other configuration A5 and A7 respectively, while Pilot 2 rated it A3. The spread of four rating points was the largest recorded during this program and is impossible to rationalize on any basis other than the variability of pilot opinion.

Evaluation

The reduced capability for holding constant altitude represents the worst feature of the wing-and-tail-off configuration in deceleration. The control rate data indicated a higher work load with this configuration. The amplitude data showed a requirement for large longitudinal inputs as the aircraft decelerated into the region where the download on the tail becomes a problem. Pilots agreed that work load was higher with wing and tail off but disagreed on their ratings of performance and their Cooper-Harper ratings.

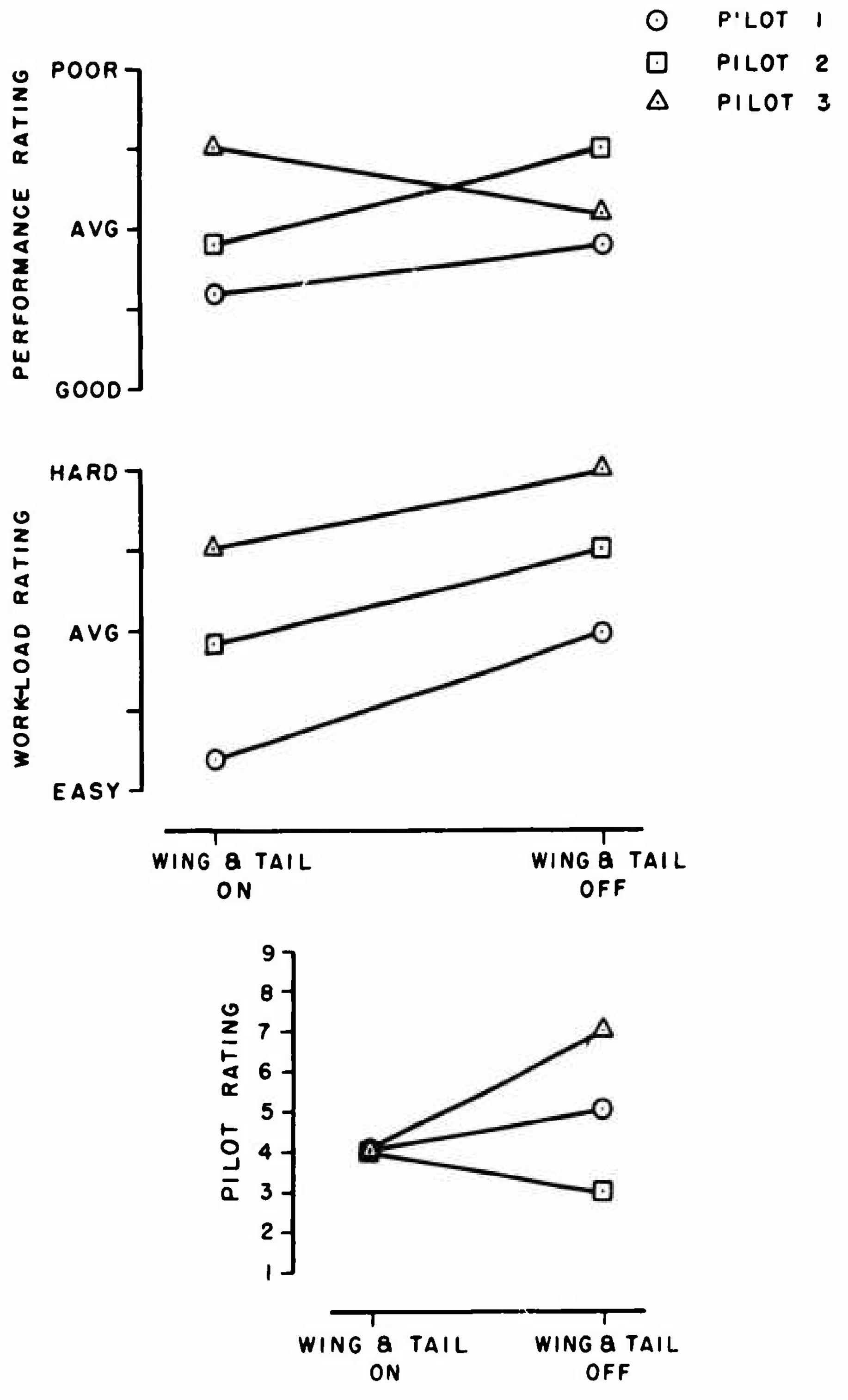


FIGURE 67. DECELERATION — PILOT OPINION

FIGURE-8 TURNS

The figure-8 turn maneuver consisted of two linked 360° turns which were to be flown at constant altitude and airspeed. As with the previous tasks, each pilot flew five trials with each aircraft configuration.

Objective Data

The altitude and airspeed errors are shown in Figure 68. Significant differences between configurations were found in both the altitude standard deviation and the average absolute altitude error, Table XII. Both of these measures show better altitude control precision with the wing and tail on. Differences in airspeed slightly favored this configuration but were not sufficiently large to reach significance.

Work-Load Measures

Attitude Rate

Figure 69 illustrates the relationship between configuration and attitude rate activity. Roll, pitch and yaw rate standard deviations were significantly greater with the wing and tail off. This is indicative of difficulty in holding the aircraft in a stable attitude during the course of the maneuver, and convincingly shows the beneficial effects of the compound configuration at higher speeds.

Control Positions

Figure 70 presents the mean control positions, their standard deviations and maximum input values. Once again the forward shift in longitudinal stick trim due to horizontal stabilizer download is present in the wing-and-tail-on configuration. In this case, however, the longitudinal excursions, as evidenced by the standard deviation and the envelope of motion, are greater with the wing and tail off. This, evidently, is due to the lack of pitch stability with the horizontal tail removed. Lateral cyclic, collective and pedals do not reflect differences due to configuration.

Control Activity

Control position, control rate, and control steady time are shown in Figure 71. The change in configuration from wing and tail on to wing and tail off produces increases in longitudinal cyclic control amplitude and rate and a decrease in steady time. This is a clear indication of increased work load due to the absence of the stabilizing influence of the horizontal tail. Lateral cyclic control shows the

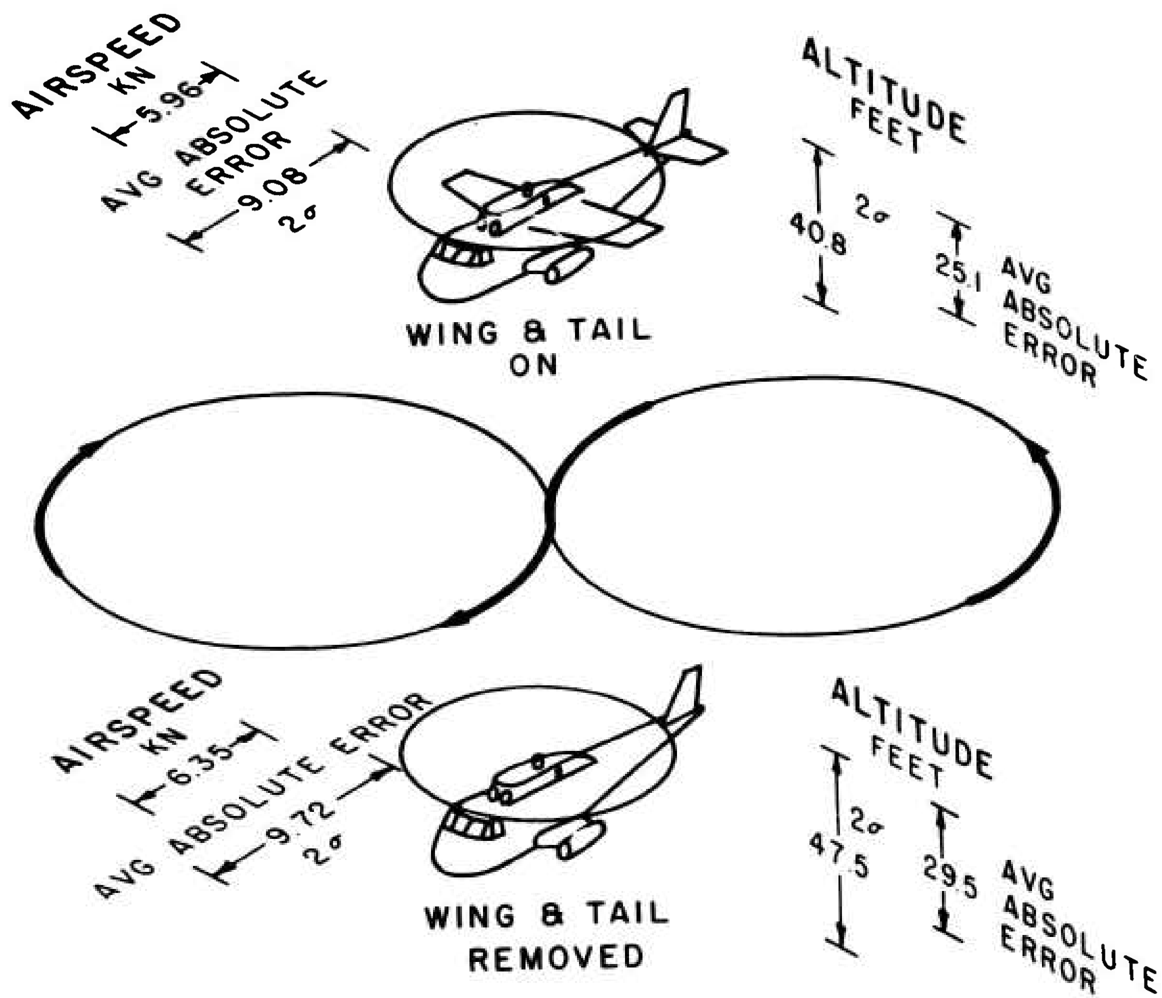


FIGURE 68. FIGURE—8 TURNS — ALTITUDE AND AIRSPEED ERROR

TABLE XII. FIGURE-8 TURNS — ANALYSES OF VARIANCE RESULTS

Parameters	Configuration A	Pilots B	A x B
PHOTO PANEL DATA			
Altitude			
Average Absolute Error	X	X	N.S.
Standard Deviation	X	N.S.	N.S.
Airspeed			
Average Absolute Error	N.S.	N.S.	X
Standard Deviation	N.S.	N.S.	X
TAPE DATA			
Roll Rate Standard Deviation	X	X	X
Pitch Rate Standard Deviation	X	X	X
Yaw Rate Standard Deviation	X	X	X
Longitudinal Cyclic			
Average Position	X	X	X
Average Rate	X	X	X
Steady Time	X	X	X
Lateral Cyclic			
Average Position	X	X	X
Average Rate	X	X	X
Steady Time	X	X	X
Collective			
Average Position	N.S.	N.S.	X
Average Rate	N.S.	N.S.	N.S.
Steady Time	N.S.	N.S.	N.S.
Pedals			
Average Position	N.S.	X	N.S.
Average Rate	X	N.S.	N.S.
Steady Time	N.S.	N.S.	N.S.

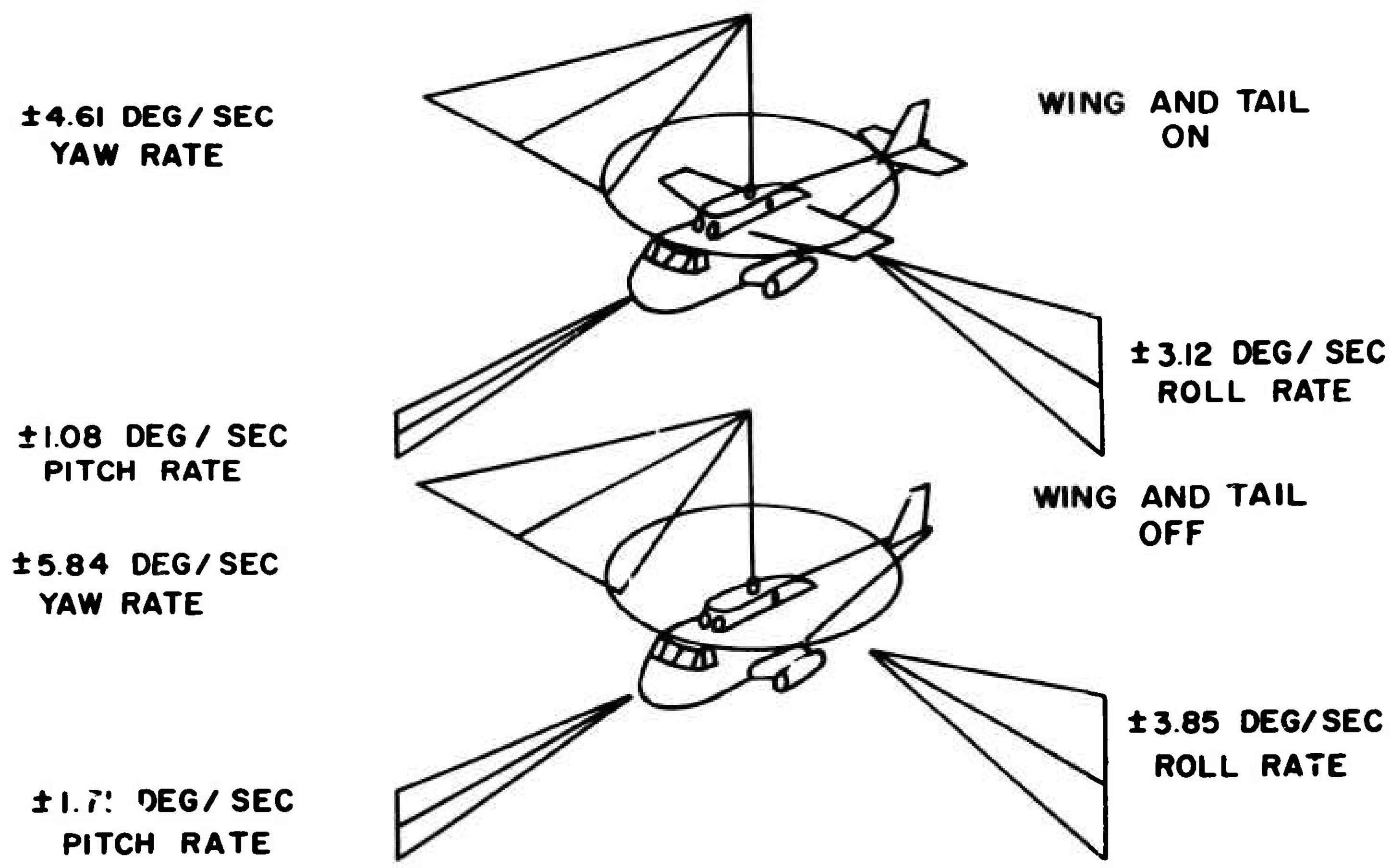


FIGURE 69. FIGURE–8 TURNS – ATTITUDE RATES

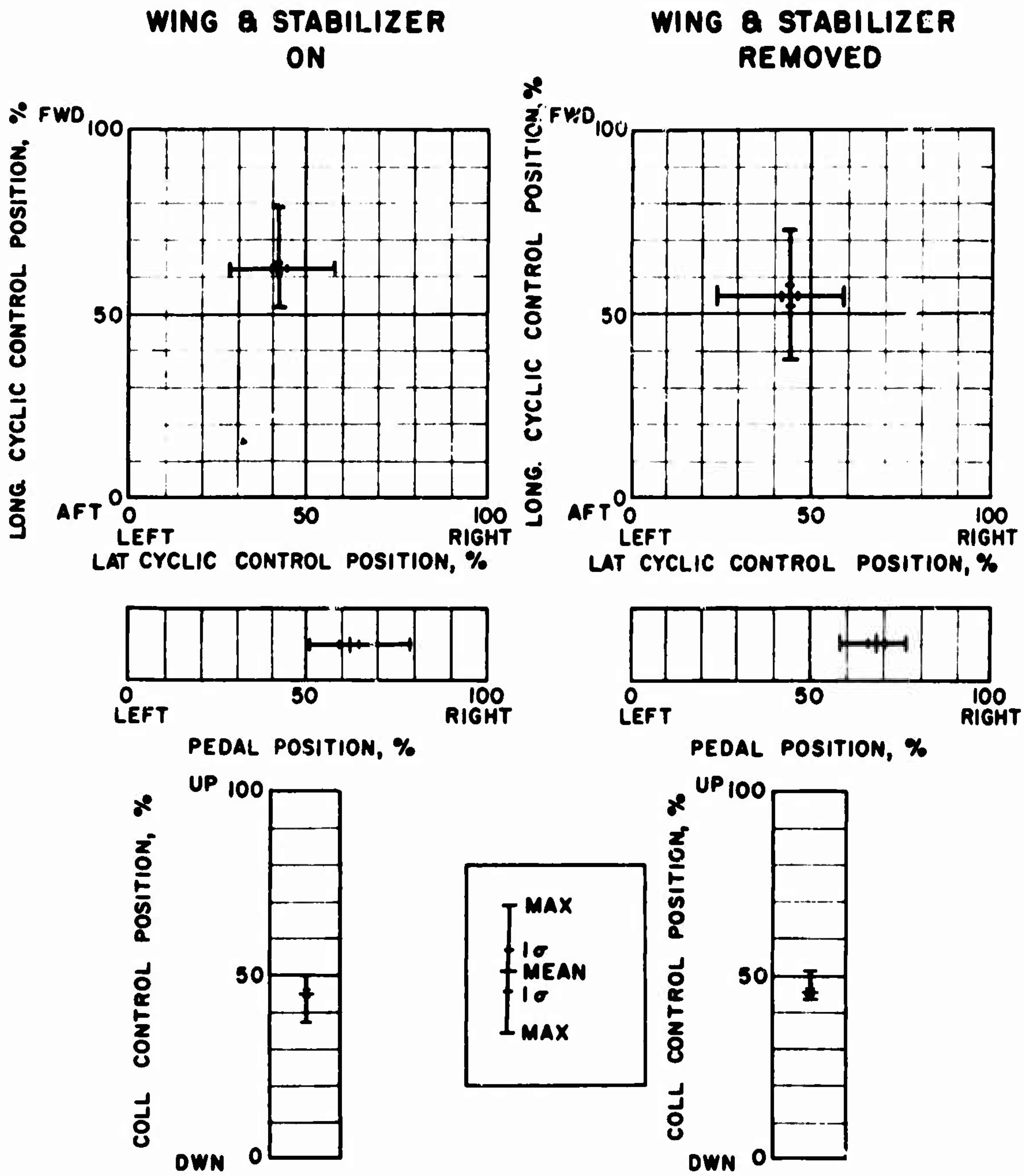


FIGURE 70. FIGURE—8 TURNS — CONTROL POSITIONS

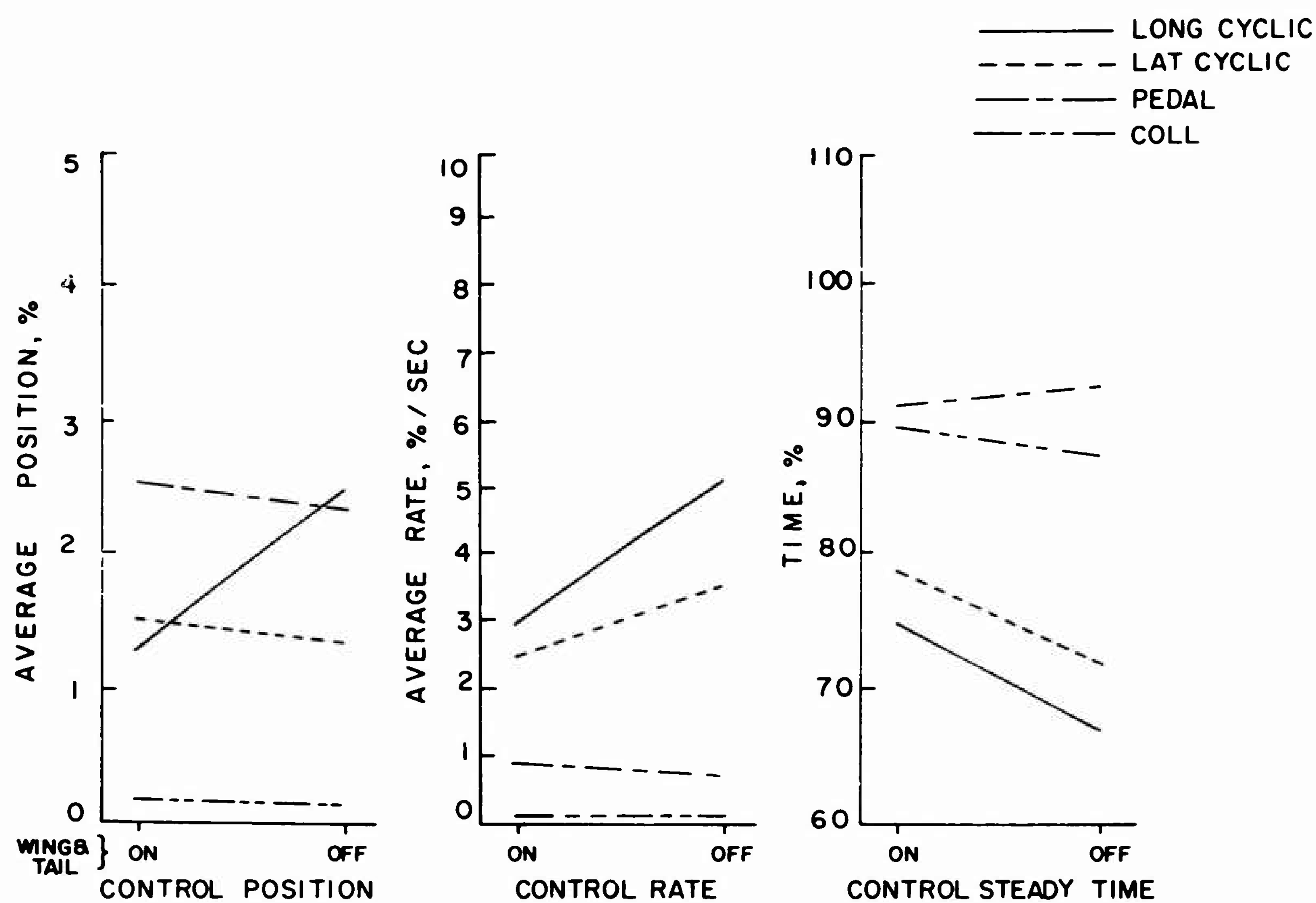


FIGURE 71. FIGURE—8 TURNS — CONTROL POSITIONS, RATES AND STEADY TIME

same increase in rate and decrease in steady time, but has a greater amplitude with the wing and tail on. This is apparently due to the greater lateral input required to overcome the roll damping of the wing when the roll angle is reversed at the mid point of the figure-8. All of these differences are statistically significant. None of the collective measures differed significantly with configuration. There was a slight, but significant, reduction in pedal rate with the wing and tail removed. This corresponds to an increase in yaw rate for the same configuration and may indicate that the pilot is failing to respond to yaw axis disturbances for some reason. One explanation could be that he is working too hard on the longitudinal and lateral degrees of freedom.

Power Spectral Density

The greater trial lengths make the power spectral density plots appear more jagged. These plots do, however, show less intertrial variability, and there is a clear configuration difference for longitudinal cyclic control. With the wing and tail on, the power is concentrated below .4 cps. However, the control amplitudes and rates (as shown previously) are not great; thus, very little control activity is required to maintain pitch control. The pattern changes markedly with wing and tail removed. In this case the input power peaks at around .2 cps and the control rate and amplitude are large. The pilot is evidently now stabilizing the aircraft in pitch, whereas with the compound configuration the tail provided the stability. The .2-cps frequency is very close to the pitch frequency induced by sideslip resulting from characteristic Dutch roll at this speed.

Pilot Opinion Data

Figure 72 illustrates the effect of configuration on the three pilot opinion measures for the figure-8 turn tasks. In rating the performance, Pilot 1 shows no difference due to configuration, while Pilots 2 and 3 had reactions opposite to each other. In their ratings of work load, Pilots 1 and 2 believed that the aircraft was easier to fly with the wing and tail off, while Pilot 3 rated this configuration as more difficult. The Cooper-Harper ratings show that Pilot 1 rated the two configurations A4. Pilot 2 rated the wing-and-tail-on configuration A6 and the wing-and-tail-off configuration A4. Pilot 3 rated the wing and tail on configuration A2 and the other configuration A6. This wide diversity of opinion is again difficult to rationalize on any basis other than the natural tendency of humans to allow factors beyond the scope of the study to influence their opinions.

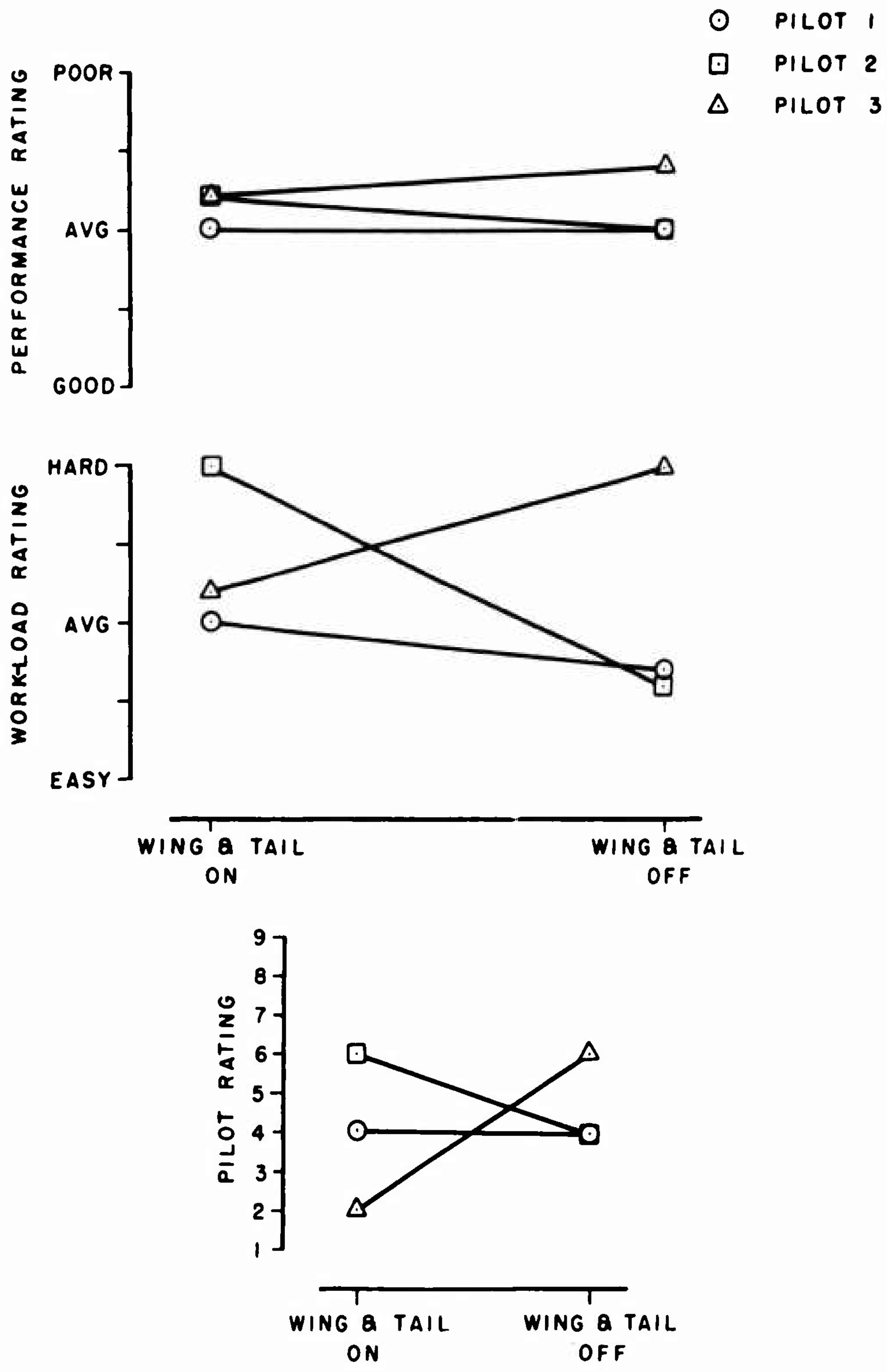


FIGURE 72. FIGURE—8 TURNS — PILOT OPINION

Evaluation

The compound configuration appears clearly superior in precision altitude control, roll and pitch rate stability, and lower control input rates. The power spectral density data also show differences favoring the wing-and-tail-on configuration. The pilot opinion data are, however, not as clear.

CONCLUSIONS

1. The most important conclusion is that no single type of data adequately presents the total picture of the aircraft handling qualities in performing mission-related tasks. Pilot opinion, control activity, and task performance precision each reveal an aspect of the situation not seen in the other two. Thus, a combination of the three data types is necessary to adequately describe the complex set of parameters which define an aircraft's flying and handling qualities.

2. Measuring task performance precision is difficult in the flight test situation. The camera techniques employed for the hover and air-taxi tasks were tedious and time consuming but provided a good method of measuring and recording task performance precision.

3. Measurement of task performance precision is necessary, because even where measured performance is similar, significant differences in pilot work load required can be observed between the configurations for the same task performance precision level.

4. Measures of control rate and amplitude are sensitive to configuration differences. Longitudinal stick rate and amplitude never failed to reveal statistically significant differences between configurations. The same measures for lateral control were almost as good, with rate and amplitude each failing only in one case to reveal these differences.

5. Pilot opinion measures can not be used as absolute flying and handling qualities evaluation parameters. Some diametrically opposed opinions were expressed by the program pilots regarding the effects of configuration changes on flying and handling qualities. In addition, individual differences are evident throughout all of these data. The statistical analysis of these data is more difficult than of the other data collected in this study.

6. Control stick rate is the measure which best predicts pilot opinion of work load. This correlation was checked for all hover tasks except air taxi and shows nearly the same degree of correlation in the accelerations, decelerations and figure-8 turns. For hover turns, the correlations were lower but in the same direction.

7. Magnetic tape recording of on-board measures is a must for programs of this type. Control motion and aircraft attitude analysis would have been impossible without it.

8. Careful selection of measures used in specification of task performance precision requirements is imperative. Such requirements have been proposed for inclusion in both general and special aircraft handling qualities specifications. Figure 73 shows that whether or not a requirement is met depends on the type of measure taken and the height above the ground where the hover is performed.

9. In near-hover conditions the rotor downwash effects on the horizontal tail produce random pitch disturbances. However, these disturbances improve hovering precision.

10. The pilot can overcome changes in aircraft flying and handling qualities by adjusting his work load to maintain a constant level of task performance precision.

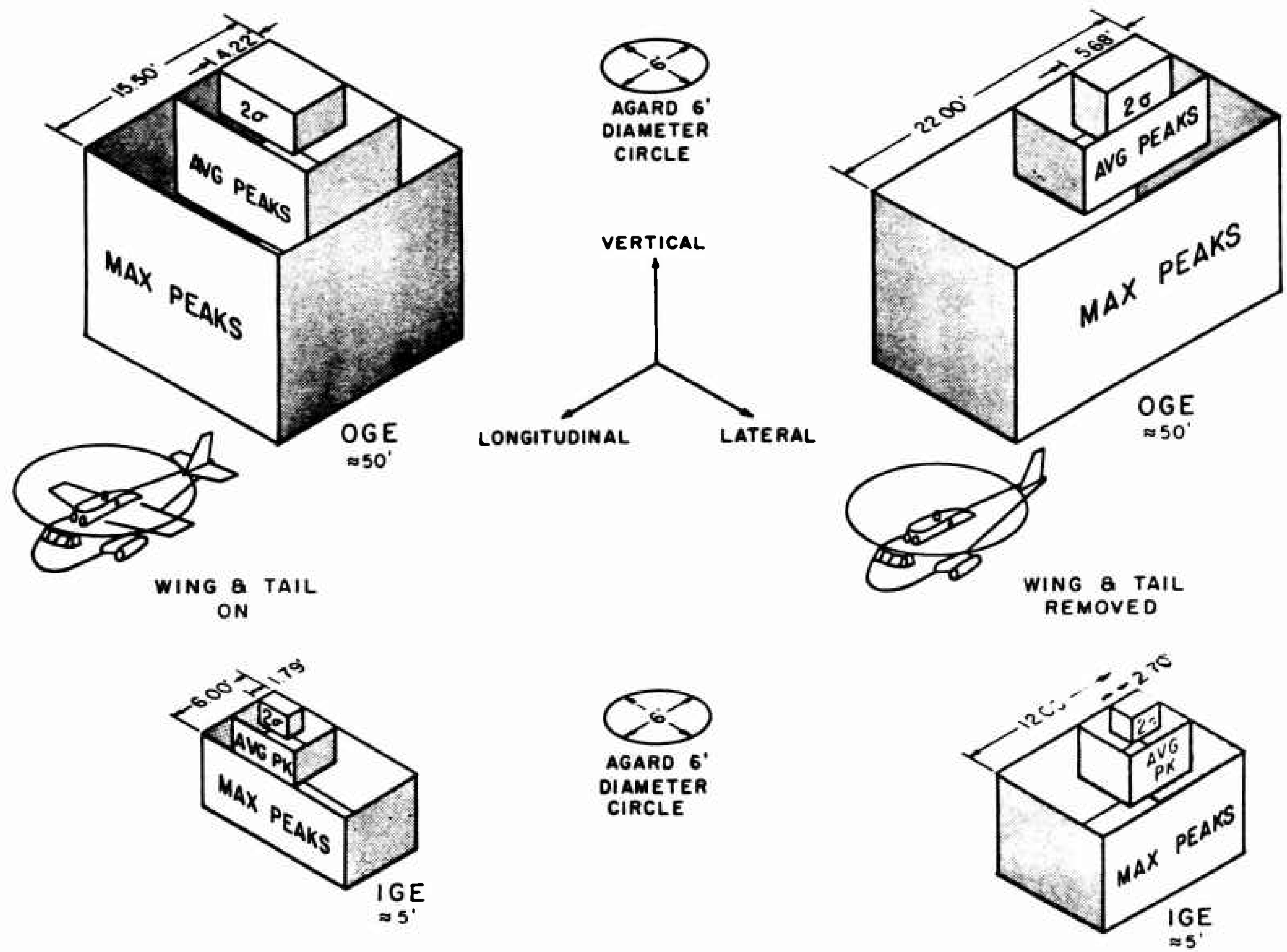


FIGURE 73. EFFECT OF TYPE OF MEASURE ON HOVER PERFORMANCE DATA

RECOMMENDATIONS

1. Conduct additional research on combined measures of opinion, work load, and precision performance with a variable-stability aircraft or simulator. Work-load measures should include secondary tasks and physiological measures. Vehicle dynamics should be varied over a wide range in order to determine sensitivity of measures and to evaluate their generality.

2. Develop a system for automatic measurement and recording of aircraft displacements, thus avoiding a frame-by-frame analysis of camera data.

3. Collect control motion and aircraft displacement and attitude data on magnetic tape for a wide variety of aircraft and programs for evaluation of design parameter influence on task performance capability and further development of task performance evaluation techniques formulated in this study.

4. Develop cookbook techniques for power spectral density analyses of control motion data for general use and for new data analysis factors. At present, there is no such system for a user who does not want to become deeply involved in theory.

5. Use factor analysis techniques to establish parameters related by a common factor in a matrix of measures.

6. Develop task performance evaluation techniques suitable for use under field conditions to determine reasonable task performance requirements for typical missions.

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APPENDIX I

EXPLANATION OF STATISTICAL TECHNIQUES USED

ANALYSIS OF VARIANCE

Analysis of variance is a statistical technique used to determine whether the effects of more than one independent variable upon a dependent variable are significant or attributable to chance.

In this study the independent variables were pilots, aircraft configuration (wing on or wing off), and flight regime (e.g., in ground effect or out of ground effect). The dependent variable was always a performance measure, such as aircraft displacement or stick motion. The analysis of variance enabled us to determine whether significant differences existed between pilots, configurations and flight regimes, as measured by camera and tape-recording techniques.

The decision as to whether observed differences are real or due to chance is based upon an arbitrary level of probability or level of confidence. The generally accepted level of confidence is 0.05, which means that if 5 of 100 observed differences are due to chance, then the observed differences are not due to chance, but are caused by changes in the variables examined; that is, the differences are significant. The confidence level may of course be better than 0.05, for example 0.01, which means only 1 difference in 100 is due to chance; thus the probability of real, measured effects is even greater than at the 0.05 level of confidence. However, if more than 5 observed differences in 100 are due to chance, i.e., the level of confidence is less than 0.05, say 0.10, then any differences observed are concluded to be chance differences and are not significant.

So far only the main effects of the independent variables have been discussed. It remains to consider interactions between these independent variables, insofar as these interactions affect the dependent variables. Interaction is that process which is responsible for data differences not caused purely by the individual effects of the independent variables, i.e. main effects, but by a process occurring between these variables.

For example, during a study in which the effects of A and B on C are examined,"A" may produce an effect by itself, "B" may produce an effect by itself, but these two main effects may not account for all the differences. An effect due to an interactive process between A and B may be present. A study of these effects is called the analysis of variance.

The analysis of variance also allows the significance of interactions to be assessed. The same principles for establishing probability levels in the case of main effects are used for interactions. In summary, the analysis of variance allows us to evaluate the significance of experimentally induced differences. In the present study, these differences are among performance measures, and knowledge of them facilitates answers to the basic research questions about effects of parameter variation.

CORRELATION COEFFICIENT

Statistical techniques of correlation enable the experimenter to arrive at a measure of the degree of association between variables, that is the extent to which values for one variable may be predicted from knowledge of others.

In this study, these techniques were used to measure the degree of association between objective measures of performance, i.e., tape and camera data, and subjective estimates of performance, i.e., pilot opinion.

Correlation coefficients range from -1 through 0 to +1. Maximum positive association is at +1. This means that a high score on one variable is associated with a high score on the variable with which it is to be correlated; likewise, low scores correspond to low scores. Maximum negative association is at -1. This means that a high score on one variable is associated with a low score on the variable with which it is to be correlated; likewise, low scores correspond to high scores. No association, positive or negative, that is the existence of a purely random relationship between two variables, is indicated by the correlation coeffient 0.

In addition to providing a measure of the degree of association, correlational techniques allow an estimate of the probability of a particular correlation coefficient (level of association) occurring by chance. Thus, to be of use in interpreting data, a correlation coefficient must be significant; that is, the possibility of its chance occurrence must be rejected. The confidence level of 0.05, used in analysis of variance, is also applied to the correlation coefficients.

APPENDIX II

AUTO-CORRELATION AND POWER-SPECTRAL-DENSITY DATA

This section presents samples of the input data and a brief summary of the computation and interpretation of the auto-correlation and power-spectral-density plots. A description of the numerical summary scores that were calculated from the power-spectral-density data is also provided. At the end is a compilation of samples of the automatically plotted correlation and PSD data.

The data to be analyzed consisted of the control input records for all tasks, all pilots, and all five repetitions. During the flights, these data were recorded on F.M. tape and then digitized at the sampling rate of ten per second.

Both the auto-correlation function and the power-spectral-density calculations are based on the UNIVAC 1108 STAT-PACK library of statistical analysis programs.

The principle of frequency analysis of a stationary ergodic process is based on the fact that a signal (t) may be represented by a continuous superposition of sine waves. This can be expressed by the Fourier integral formula as:

$$X(f)=\int_{-\infty}^{\infty} x(t)\exp(2\Pi ift)dt$$

The auto correlation of a process may be defined as:

$$R(\tau)= \frac{1}{T}\int_{-\infty}^{\infty} x(t)x(\tau+t)dt$$

and it can be shown that the power spectrum of a signal is the Fourier transform of its auto-correlation function. Thus,

$$P(f)=\int_{-\infty}^{\infty} R(\tau)\exp(2\Pi if\tau)d\tau$$

In order to mechanize these equations for numerical computation, it is necessary to replace the integral by a finite sum. The equations used in this program are given below for the two time series. The cross correlation function is defined as:

$$r_{ij}(v)=R_{ij}(v)/(S_{i,o}S_{j,v})^{\frac{1}{2}}$$

Where $R_{ij}(v)$, the cross covariance function is given by

$$R_{ij}(v) = \frac{1}{N-v}\sum_{t=1}^{N-v}(x_{t,i}-\bar{x}_{i,o})(x_{t+v,j}-\bar{x}_{j,v})$$

with

$$\bar{X}_{i,o} = \frac{1}{N-v}\sum_{t=1}^{N-v} X_{t,i}$$

$$\bar{X}_{j,v} = \frac{1}{N-v}\sum_{t=v+1}^{N} X_{t,j}$$

and

$$S_{i,o} = \frac{1}{N-v}\sum_{t=1}^{N-v}(X_{t,i}-\bar{X}_{i,o})^2$$

$$S_{j,v} = \frac{1}{N-v}\sum_{t=1}^{N-v}(X_{t+v,j}-\bar{X}_{j,v})^2$$

In the above definitions, it is apparent that $R_{ii}(v)$ is the auto-correlation function for the i^{th} time series.

When exp. $(2\pi i f t)$ is expanded in a trigonometric form, both cosine and sine terms are present. However, for an even function only the cosine term need be retained.

Thus the normalized co- and cross-spectral density function at period p, where p = 0, 1 . . . . Q, is given by

$$f_{ij}(p) = \frac{1}{2\pi}\left\{ r_{ij}(0)+\sum_{v=1}^{m}\cos\frac{(2\pi v)}{p}k\left(\frac{v}{m}\right)\left(r_{ij}(v)+r_{ji}(v)\right)\right\}$$

where the spectral window $k(\mu) = K(v/m)$ as defined by Parzen, and used in this program is given below.

$$\begin{aligned} k(\mu) &= 1 - 6\mu^2 + 6\mu^3 && \text{when } \mu < \tfrac{1}{2} \\ &= 2(1-\mu)^3 && \text{when } \tfrac{1}{2} < \mu < 1 \\ &= 0 && \mu > 1 \end{aligned}$$

For the case of an uneven function, it is necessary to consider the quadrature spectrum which is defined by

$$q_{ij}(p) = \frac{1}{2\pi} \sum_{v=1}^{m} \sin(\frac{2\pi v}{p})k(\frac{v}{m})(r_{ij}(v)-r_{ji}(v))$$

The resulting spectrum is then given by

$$A_{ij}(p) = \{ f_{ij}^{2}(p) + q^{2}_{ij}(p)\}^{\frac{1}{2}}$$

Among the problems encountered in these calculations were the effects of trial duration and such computation parameters as the number of lags and length of the auto-correlation function plot. It was determined through sample calculations that adequate results would be obtained by using a number of lags equal to one-half of the one-tenth-second samples for each trial and an auto-correlation plot length equal to one-third the trial duration. This represented a good compromise, yielding satisfactory smoothing without sacrificing the spectral resolution unduly and meeting the requirements of the UNIVAC program.

In the interpretation of these data it is important to keep in mind that the power spectral densities are based on normalized auto-correlation functions. Information on the overall magnitude of the control input signal is lost in the normalization process, and thus the power spectral density is representative only of the relative power at each frequency. The amplitude was computed separately and has been discussed elsewhere. Due to the normalization of the auto-correlation function by dividing through by the variance, the units of the power-spectral-density plots are 1/cps.

The following numerical summary scores were calculated for each of the trials:

1. Mode frequency - The frequency where maximum power was measured, the peak frequency.
2. Median frequency - The frequency where 50% of power was applied above and 50% below.
3. Cutoff frequency - The frequency where 95% of the power is applied at lower frequency and 5% at higher.
4. Mean or balance frequency - A measure of central tendency computed by taking the product of the height at each point and its distance from zero frequency and dividing by the area under the curve.

5. Standard deviation - This measure was computed as if the power spectral density were a frequency distribution and is indicative of the spread of power around the mean value.

The following data sheets are samples of the power-spectral-density and auto-correlation plots generated from the digital computer output.

Those samples cover the data showing differences due to configuration. They are mainly restricted to longitudinal cyclic; however, lateral cyclic plots are presented for the hover and deceleration tasks.

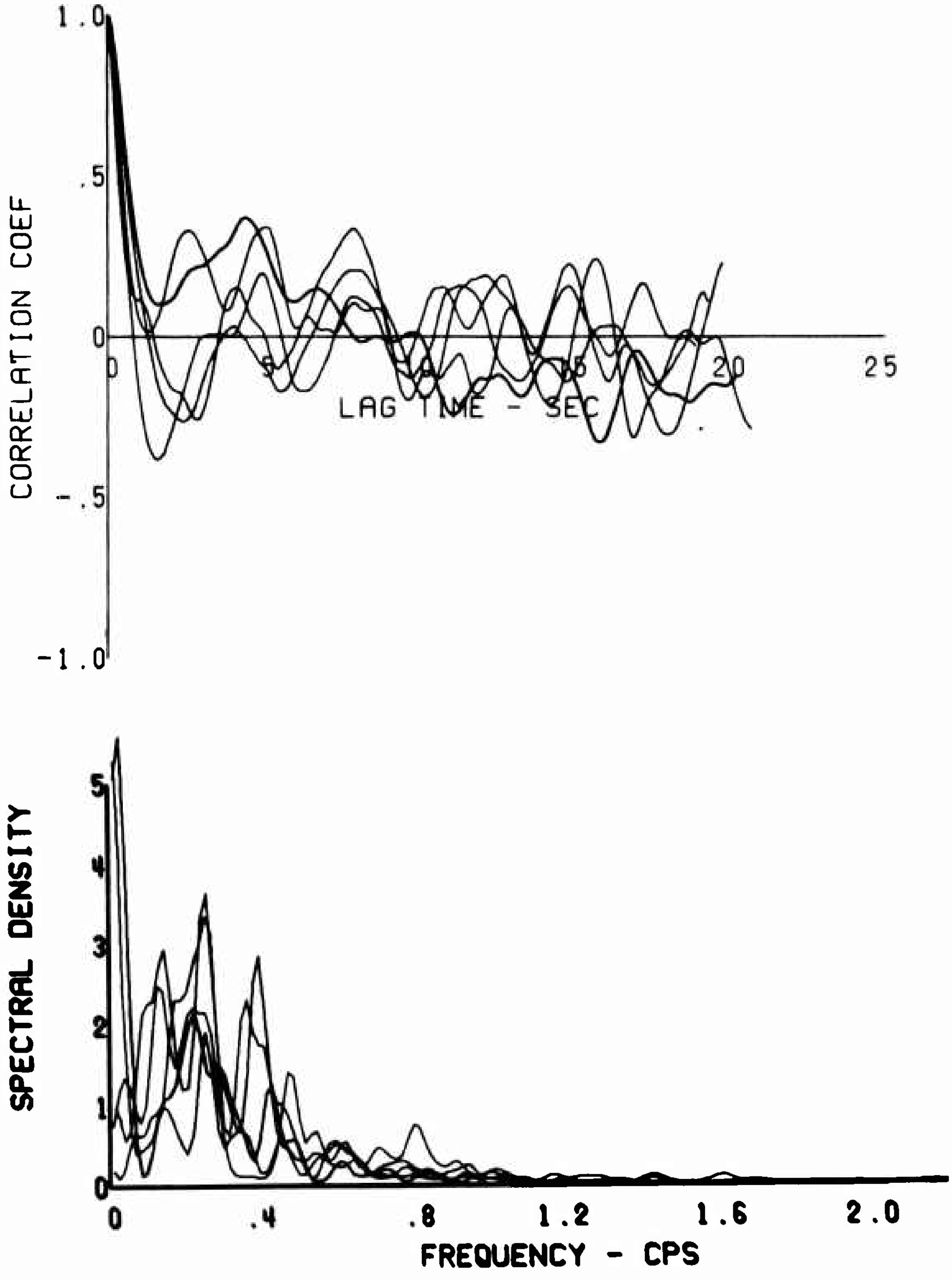


FIGURE 74. LONGITUDINAL STICK PSD, IGE HOVER, PILOT 1, WING AND TAIL ON

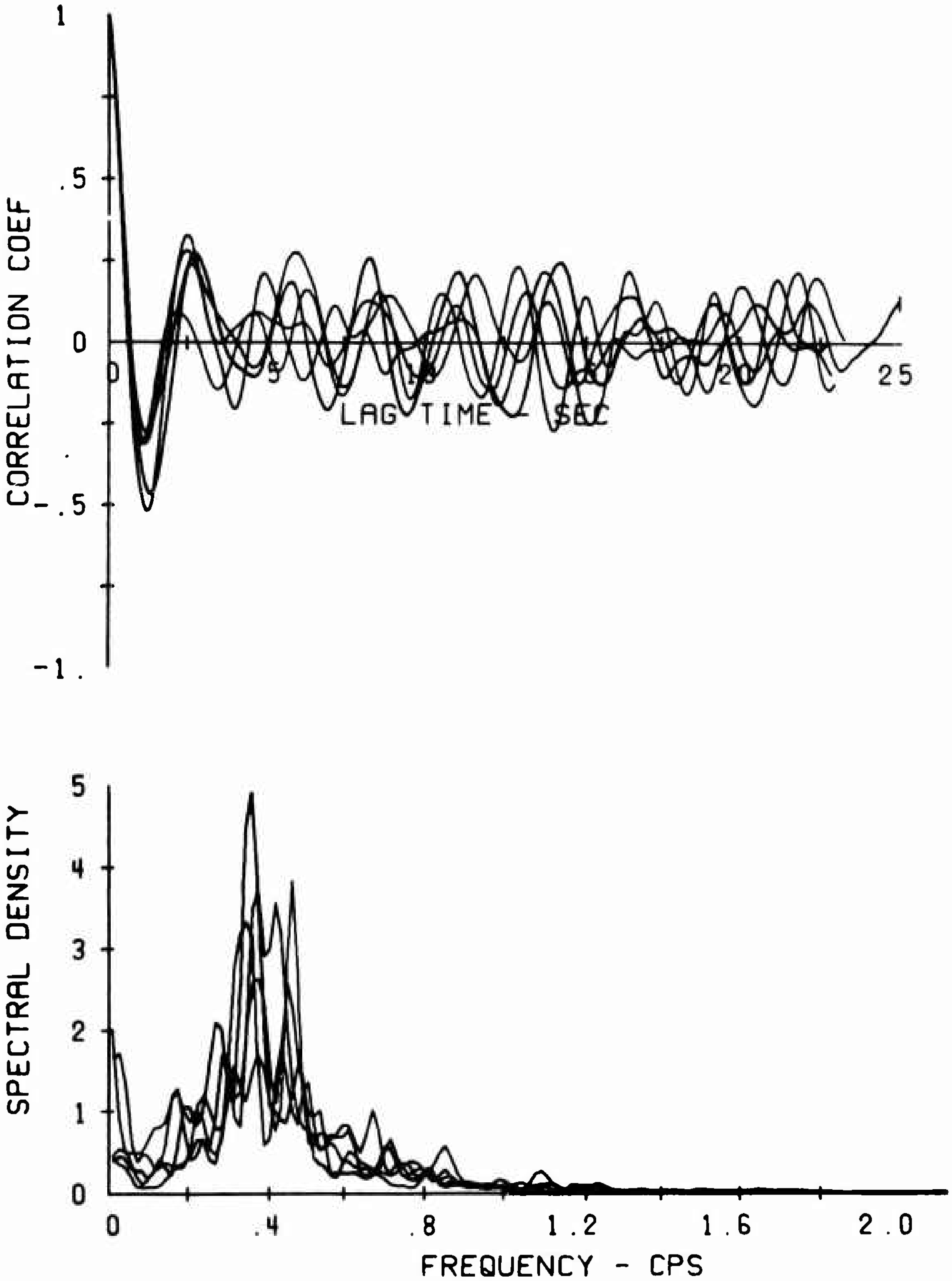


FIGURE 75. LONGITUDINAL STICK PSD, IGE HOVER, PILOT 1
WING AND TAIL OFF

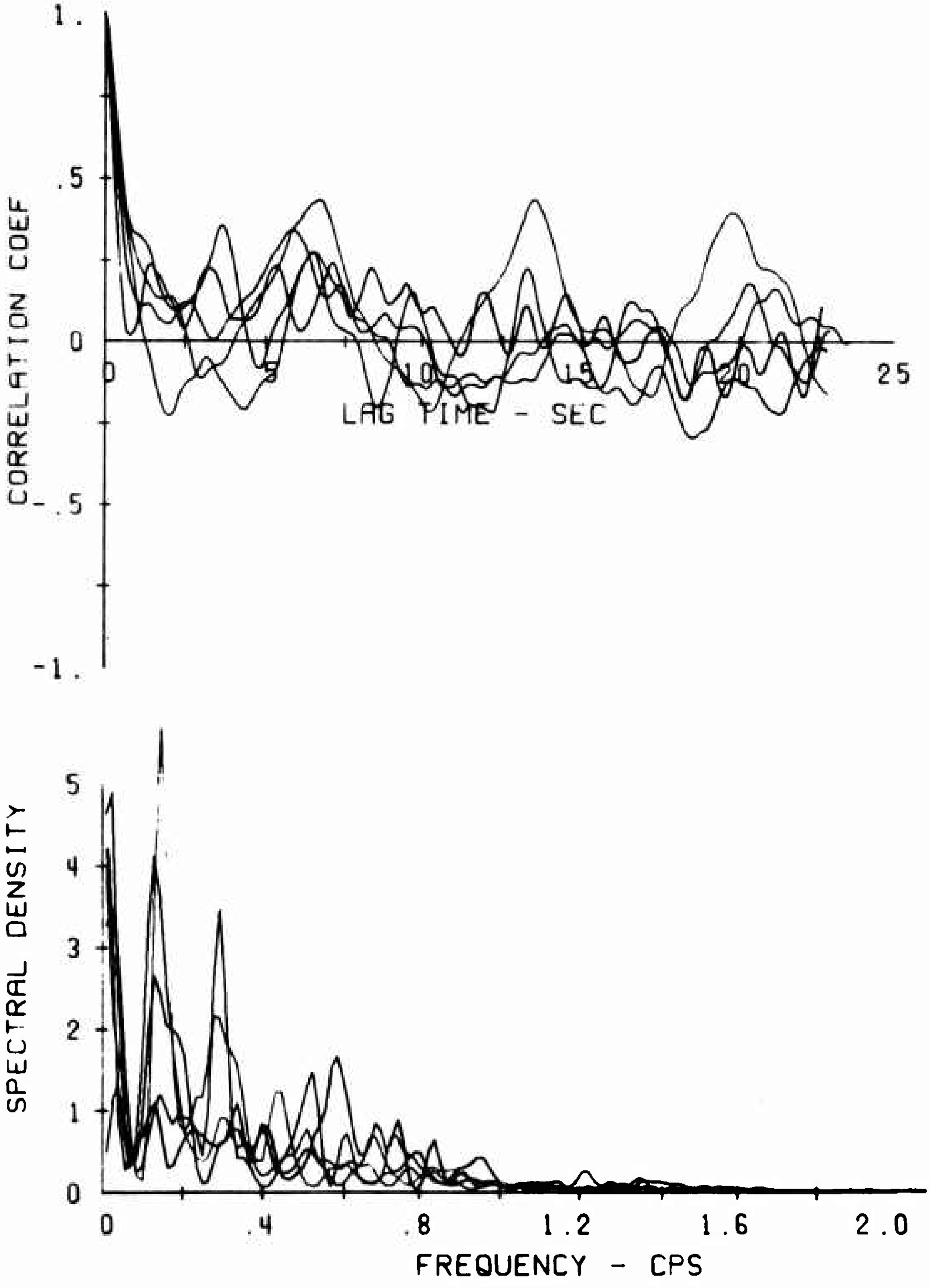


FIGURE 76. LONGITUDINAL STICK PSD, IGE HOVER, PILOT 2, WING AND TAIL ON

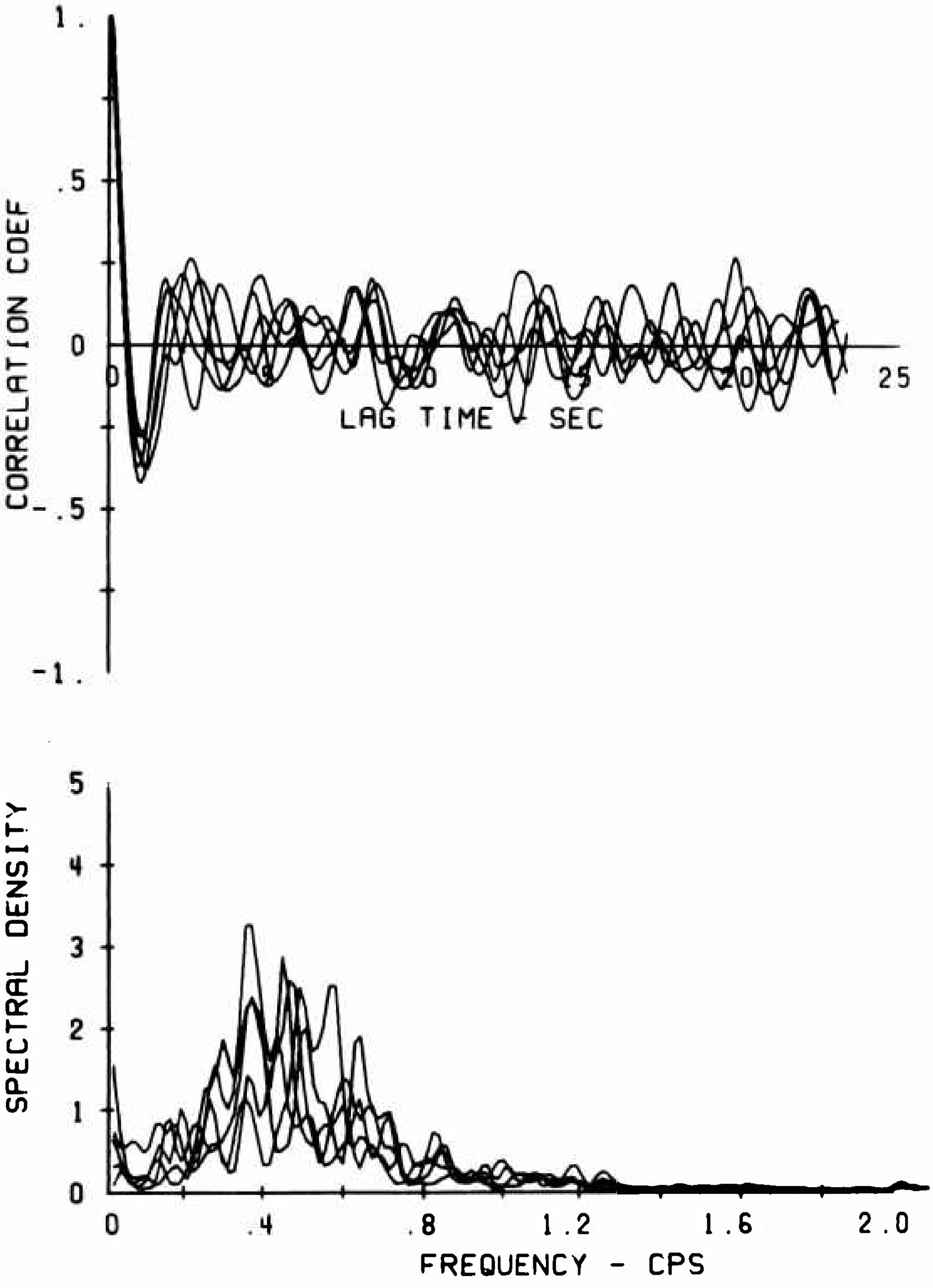


FIGURE 77. LONGITUDINAL STICK PSD, IGE HOVER, PILOT 2, WING AND TAIL OFF

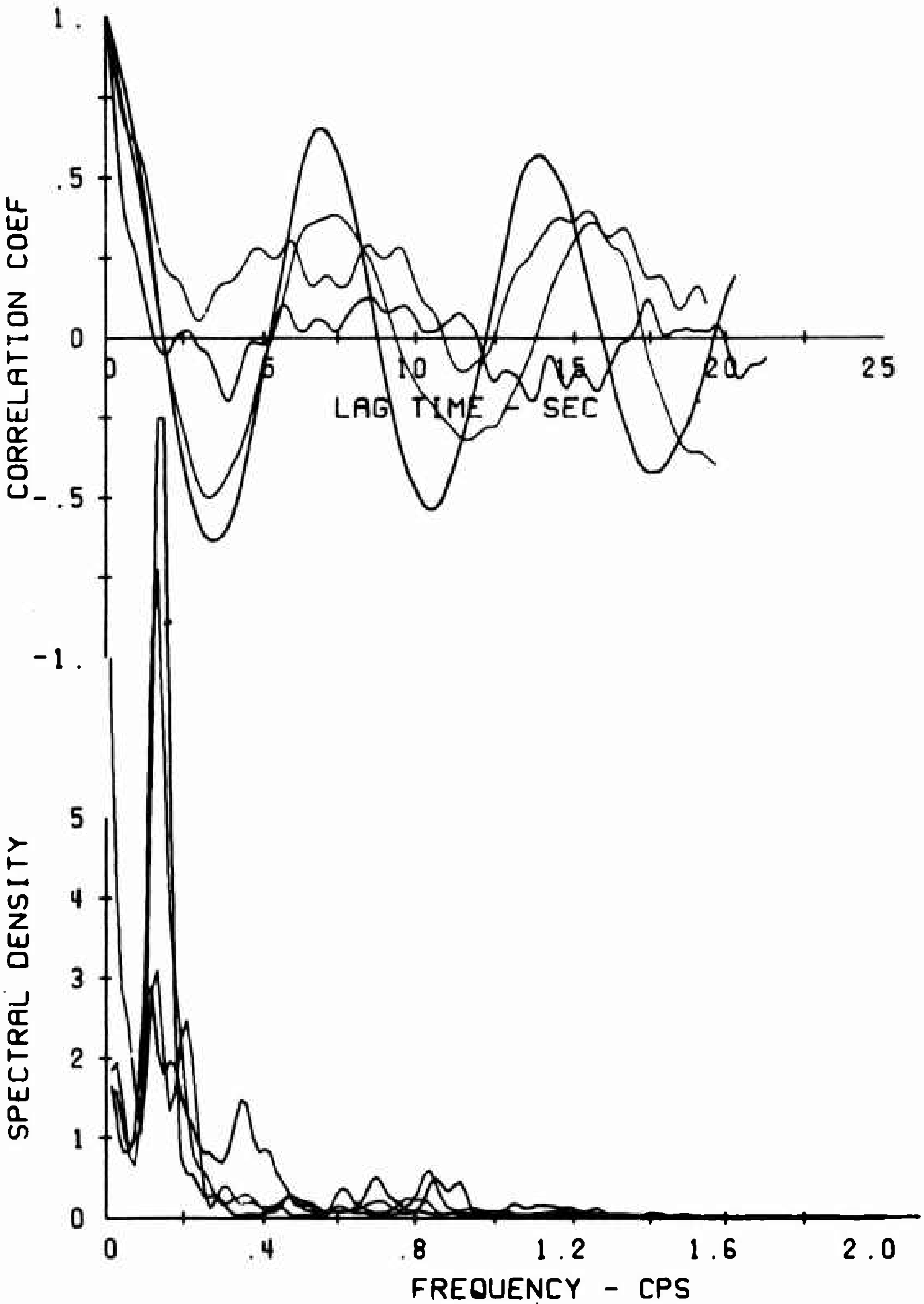


FIGURE 78. LONGITUDINAL STICK PSD, IGE HOVER, PILOT 3
WING AND TAIL ON

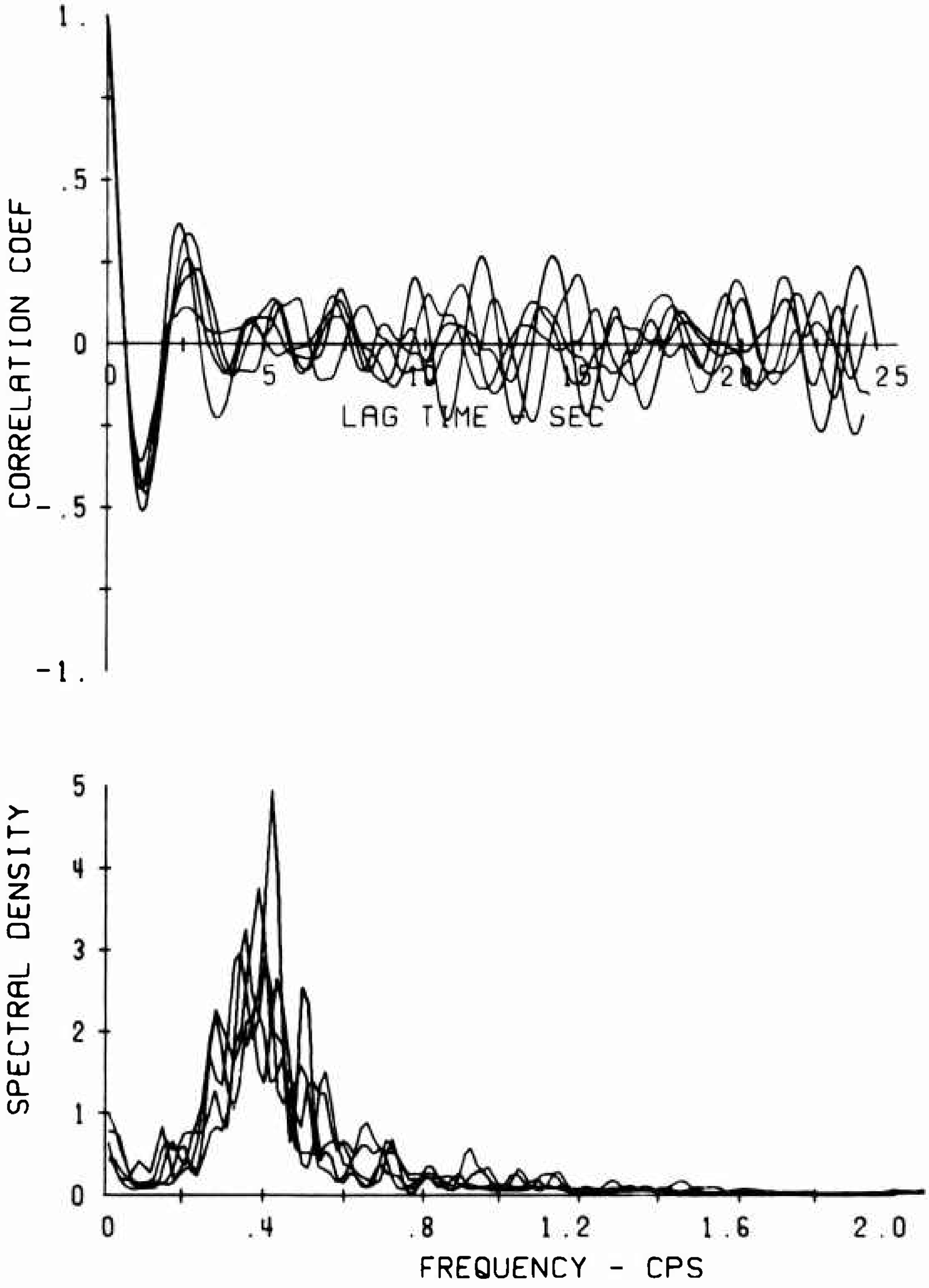


FIGURE 79. LONGITUDINAL STICK PSD, IGE HOVER, PILOT 3, WING AND TAIL OFF

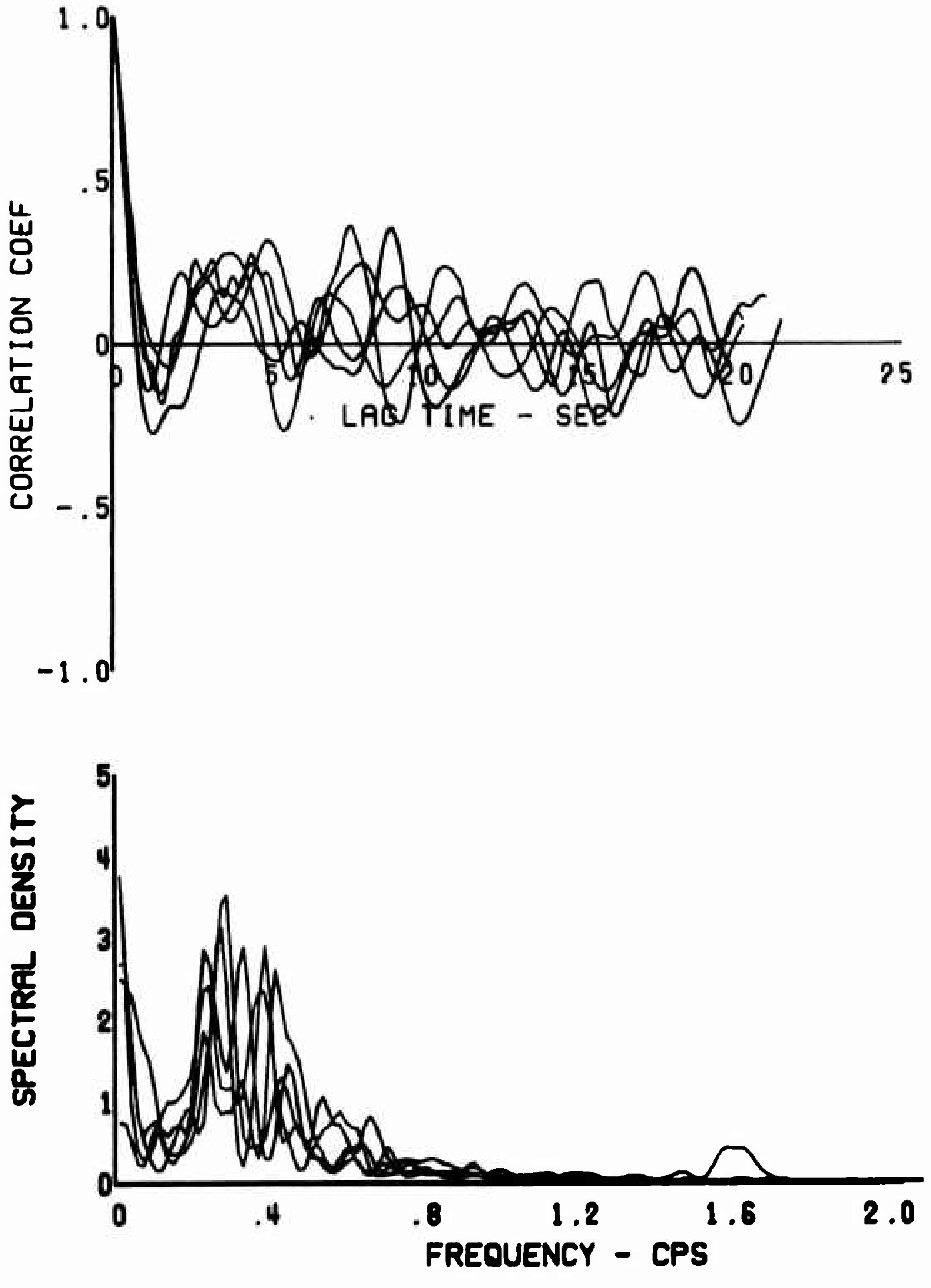


FIGURE 80. LONGITUDINAL STICK PSD, OGE HOVER, PILOT 1
WING AND TAIL ON

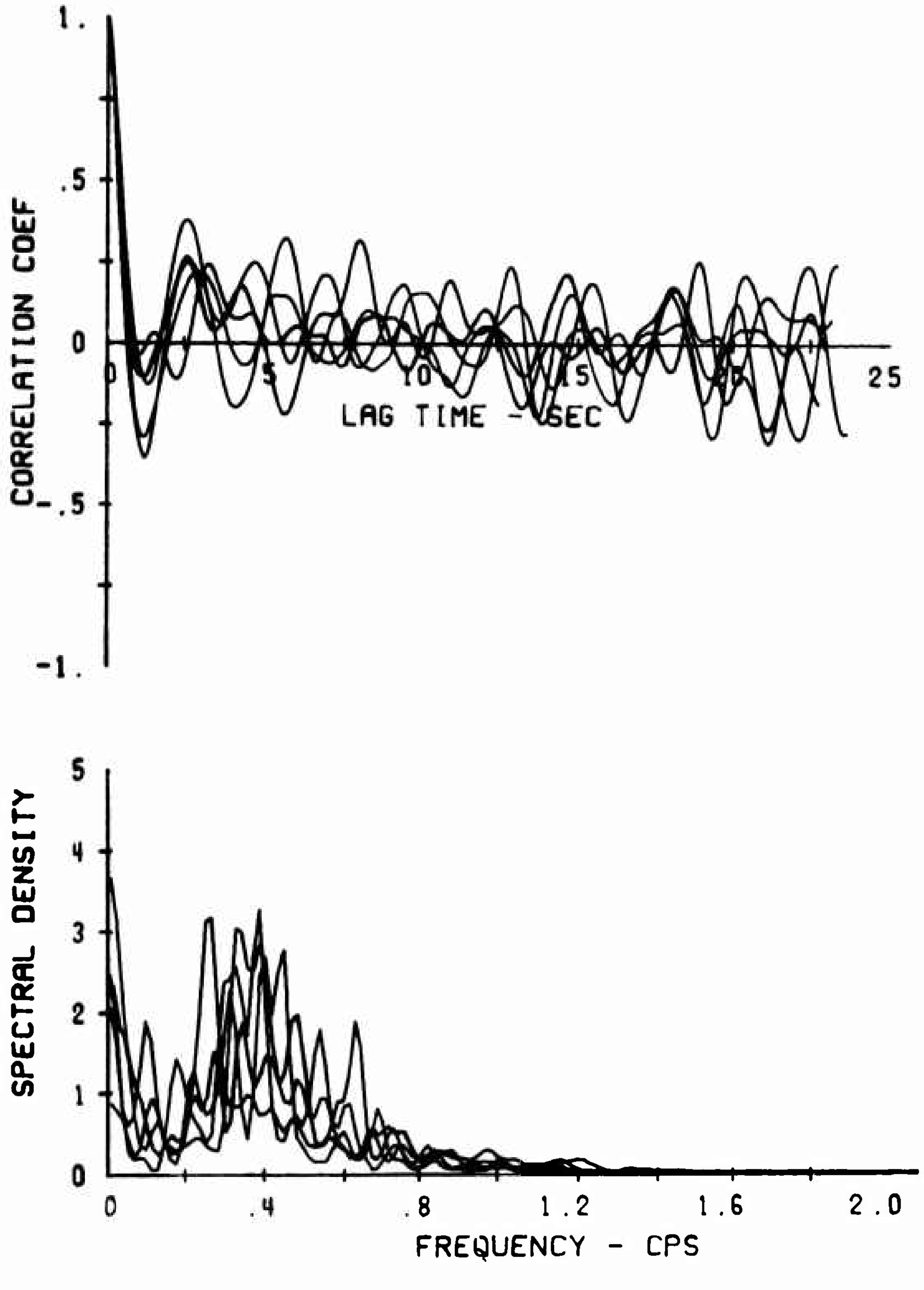


FIGURE 81. LONGITUDINAL STICK PSD, OGE HOVER, PILOT 1, WING AND TAIL OFF

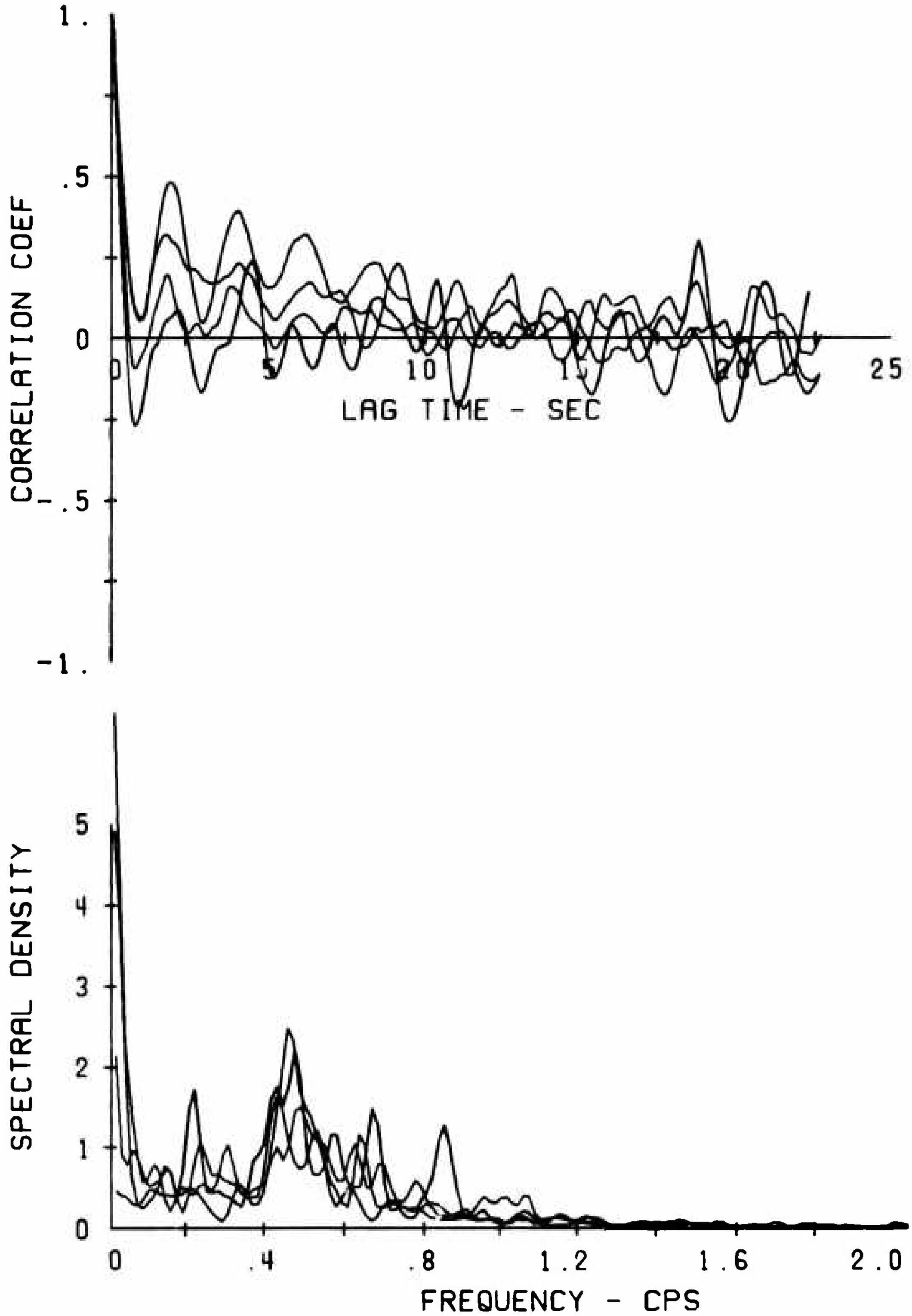


FIGURE 82. LONGITUDINAL STICK PSD, OGE HOVER, PILOT 2, WING AND TAIL ON

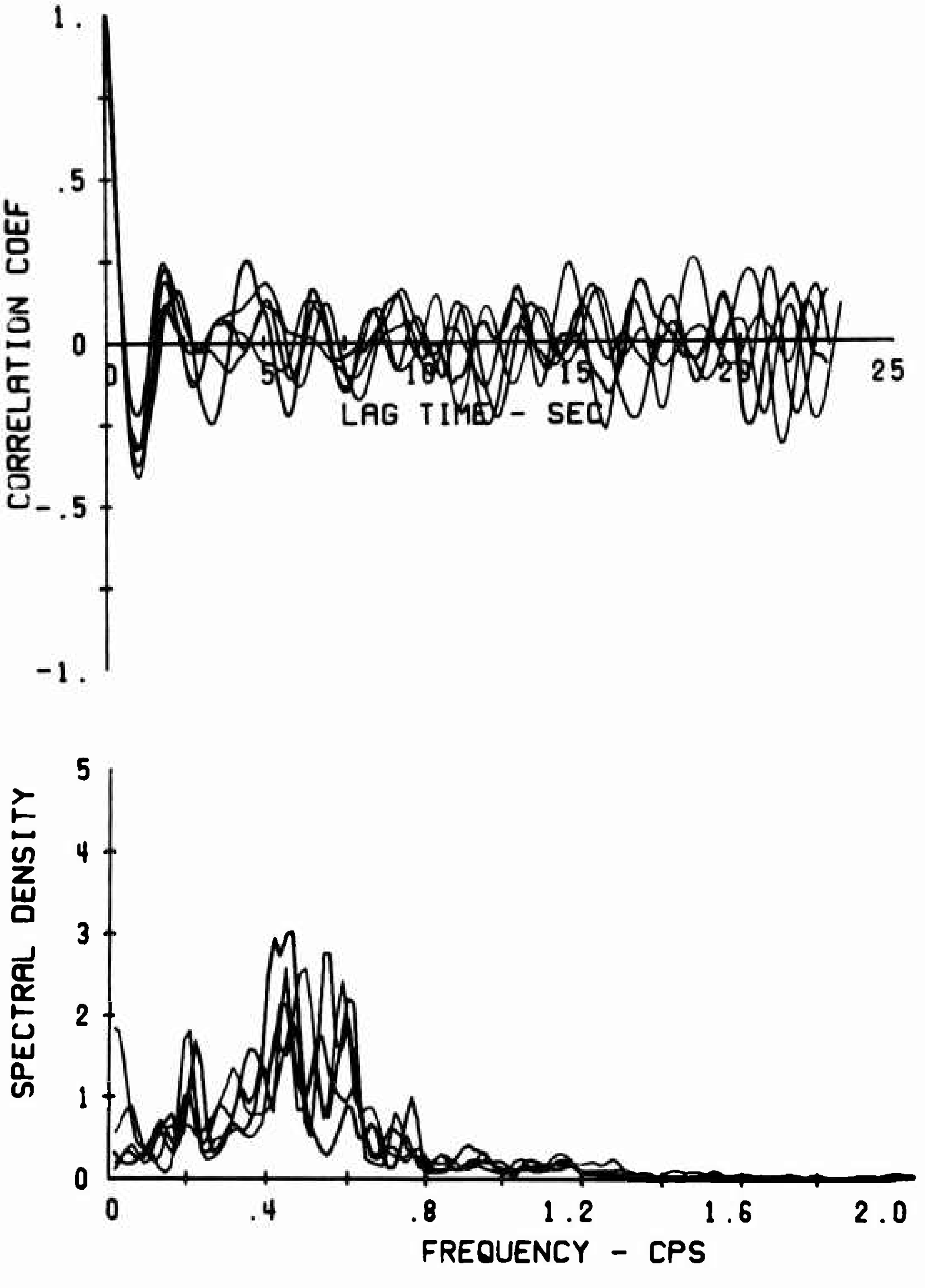


FIGURE 83. LONGITUDINAL STICK PSD, OGE HOVER, PILOT 2, WING AND TAIL OFF

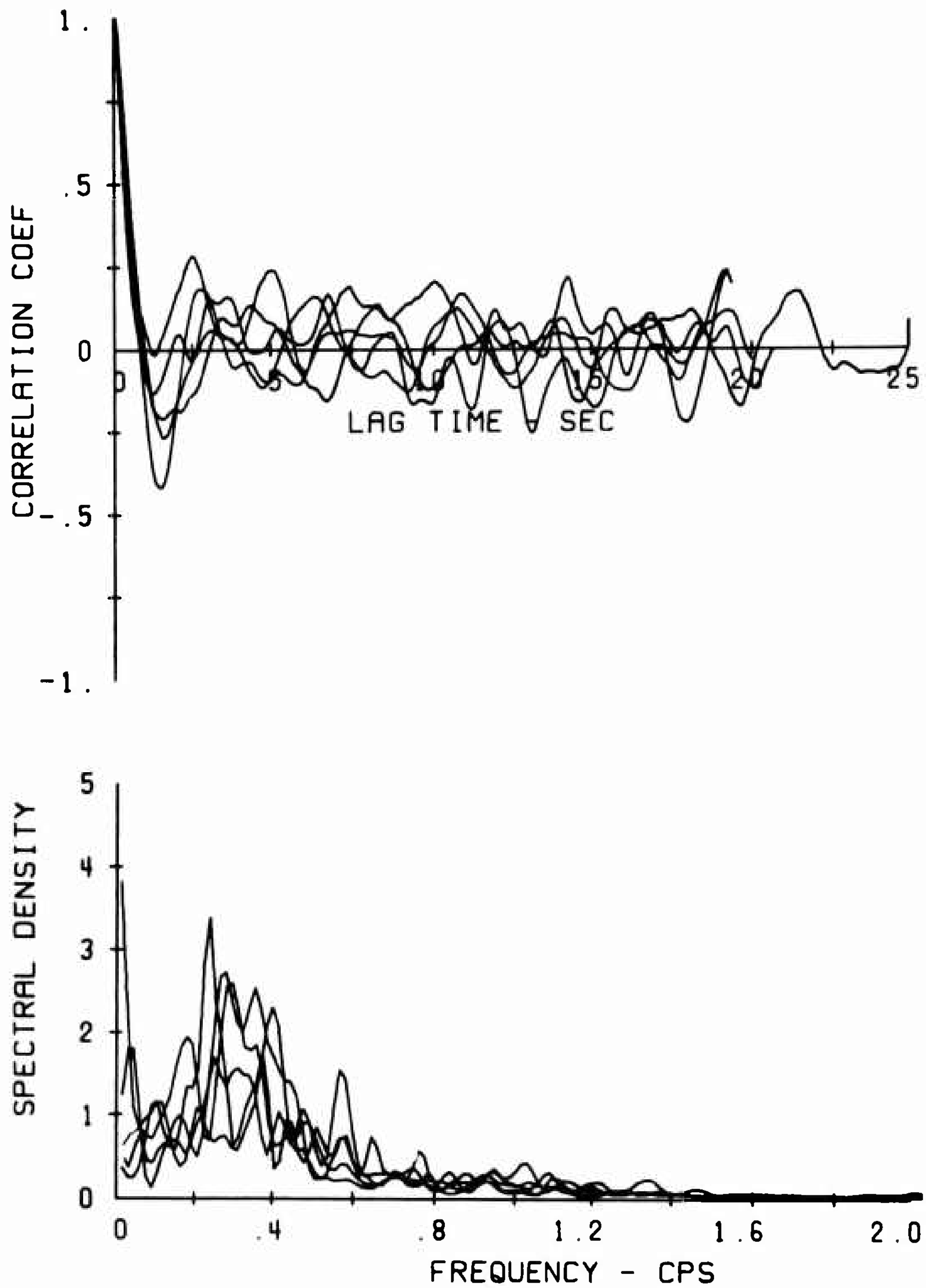


FIGURE 84. LONGITUDINAL STICK PSD, OGE HOVER, PILOT 3, WING AND TAIL ON

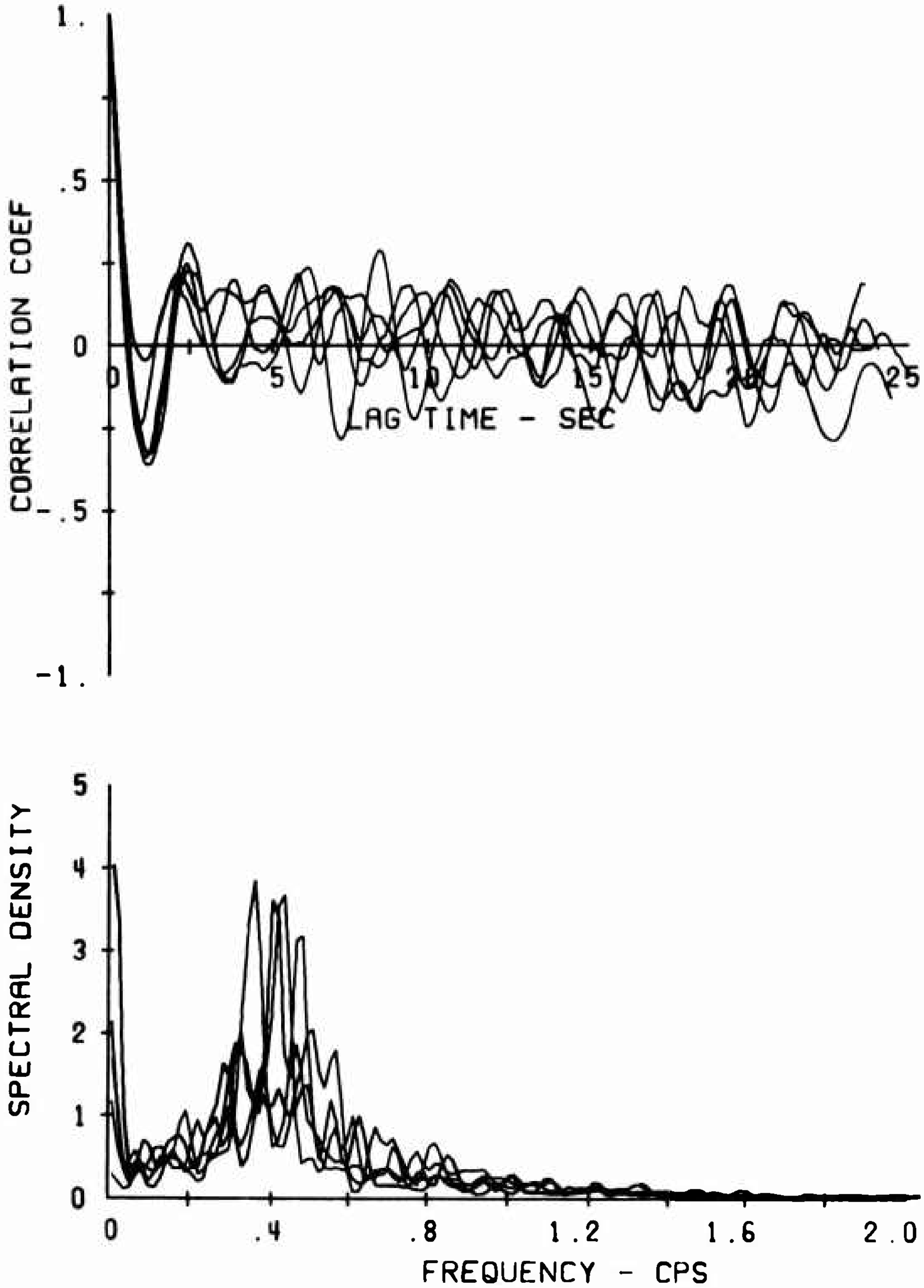


FIGURE 85. LONGITUDINAL STICK PSD, OGE HOVER, PILOT 3, WING AND TAIL OFF

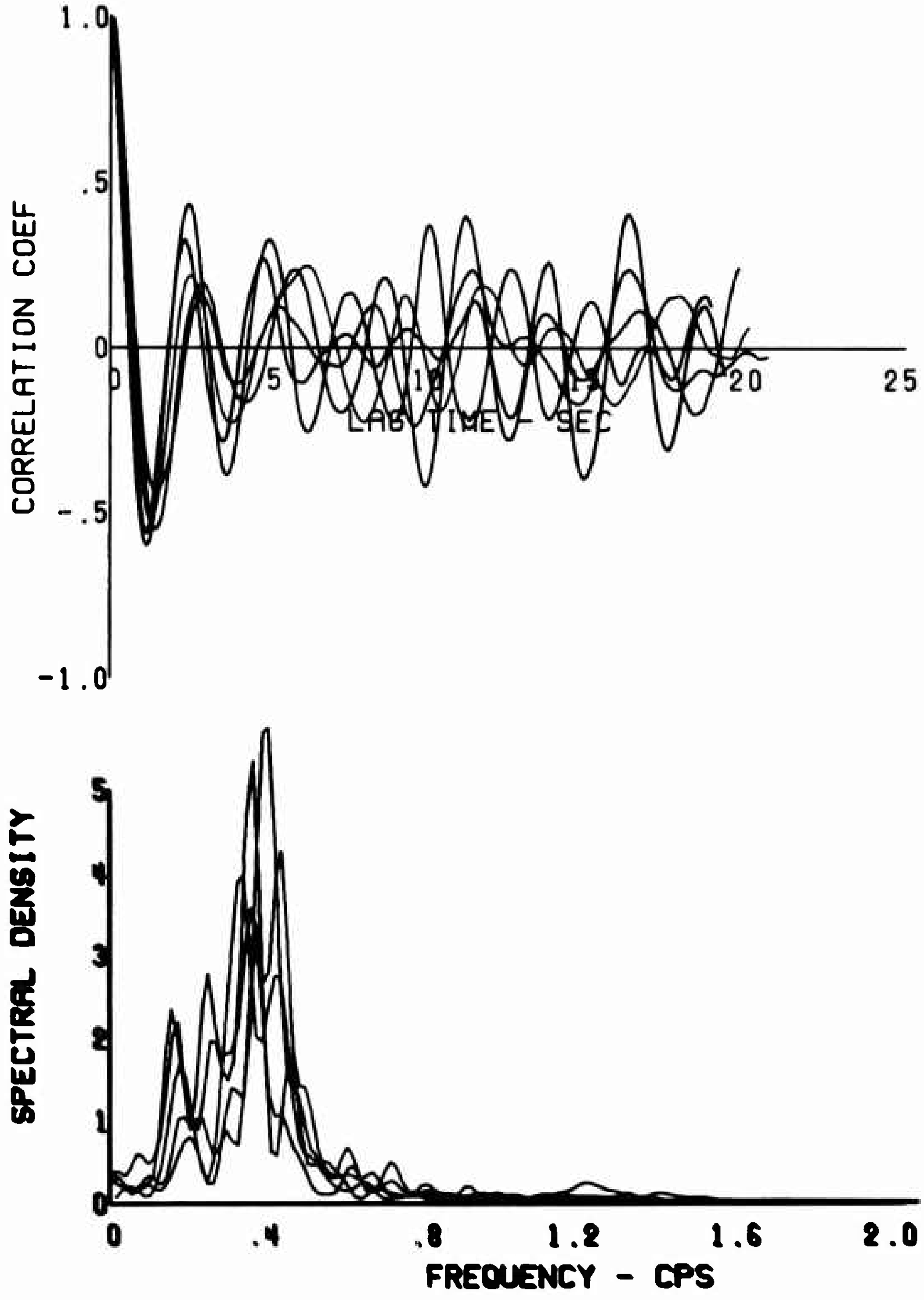


FIGURE 86. LATERAL STICK PSD, IGE HOVER, PILOT 1, WING AND TAIL ON

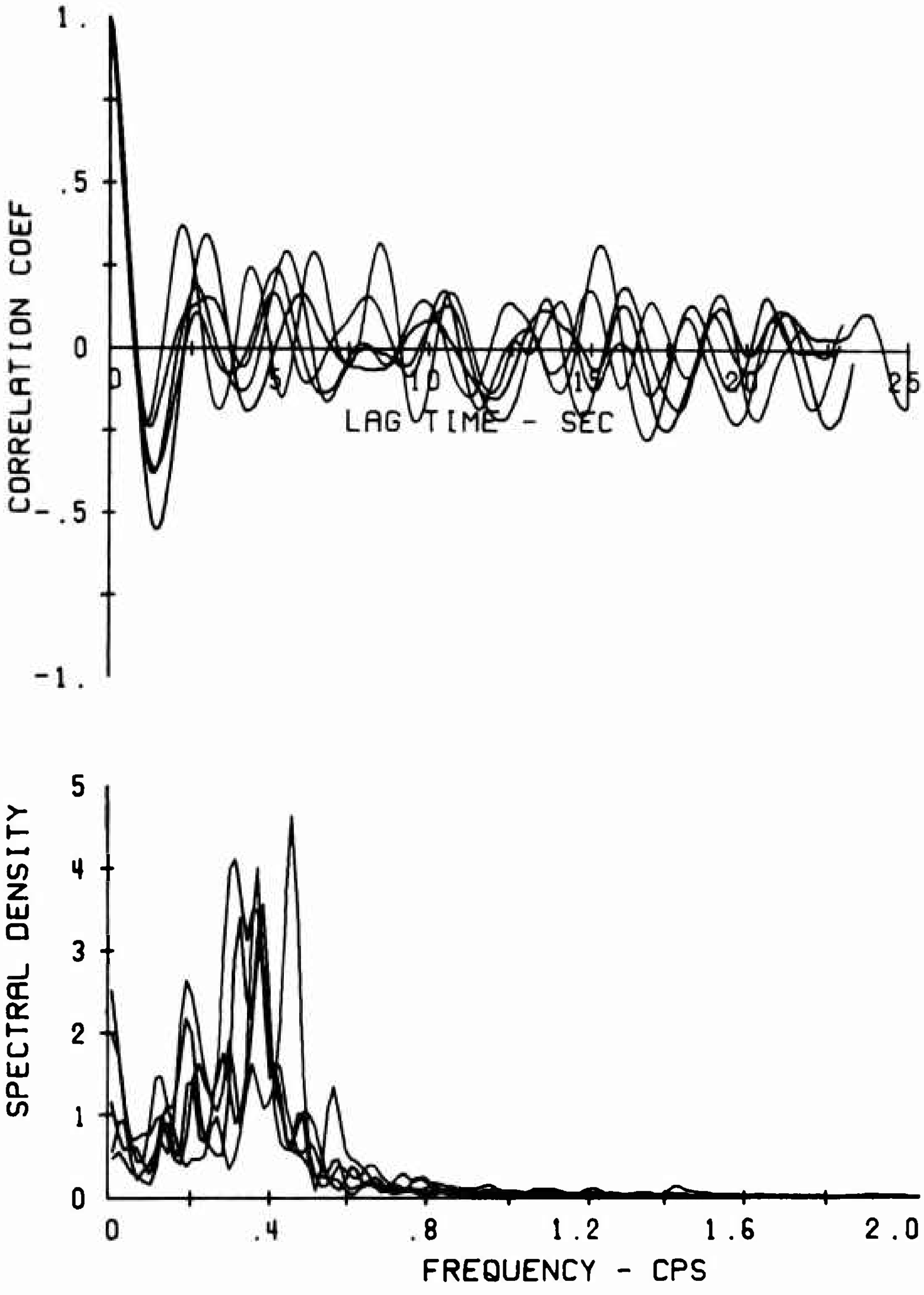


FIGURE 87. LATERAL STICK PSD, IGE HOVER, PILOT 1,
WING AND TAIL OFF

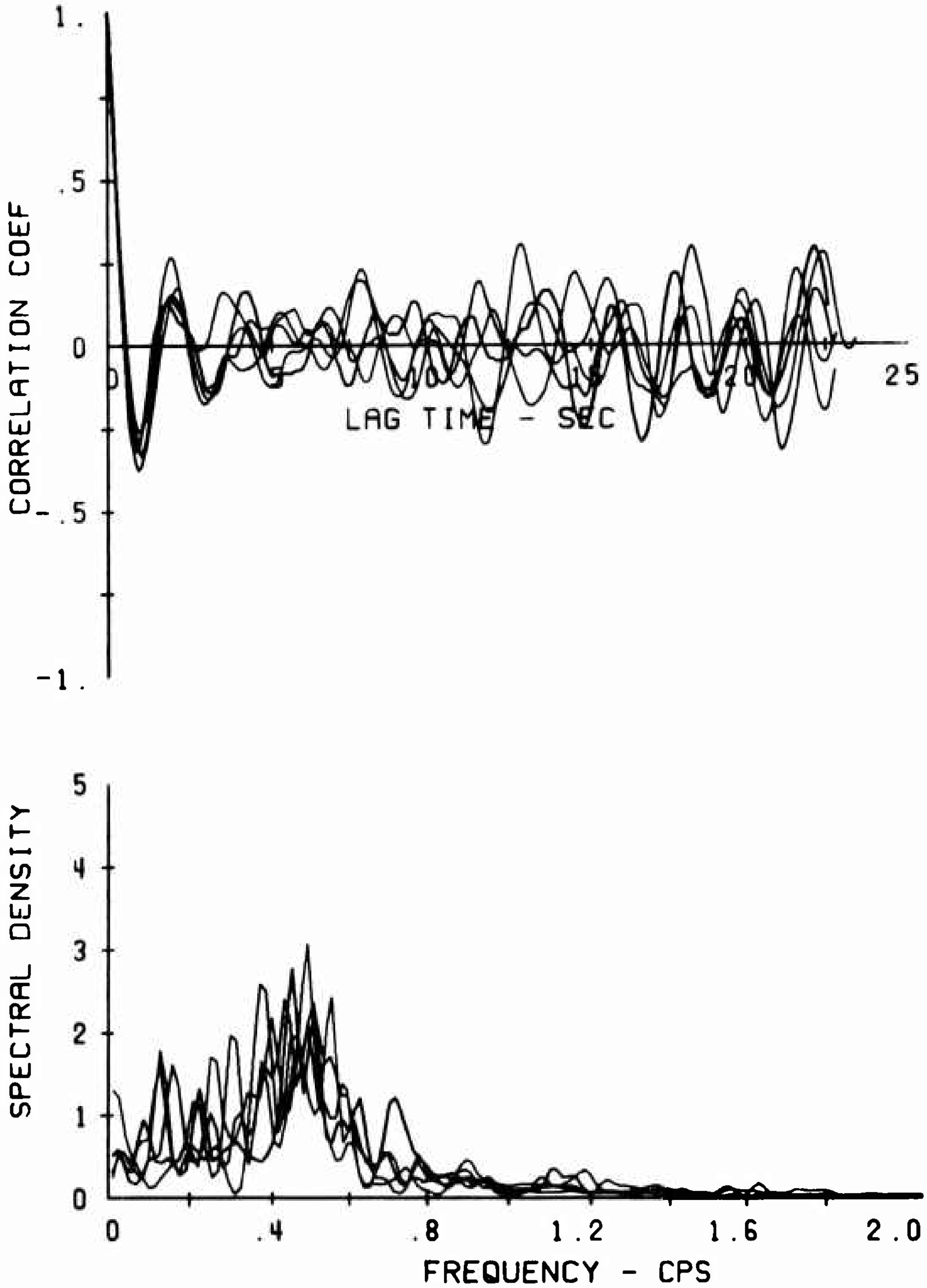


FIGURE 88. LATERAL STICK PSD, IGE HOVER, PILOT 2, WING AND TAIL ON

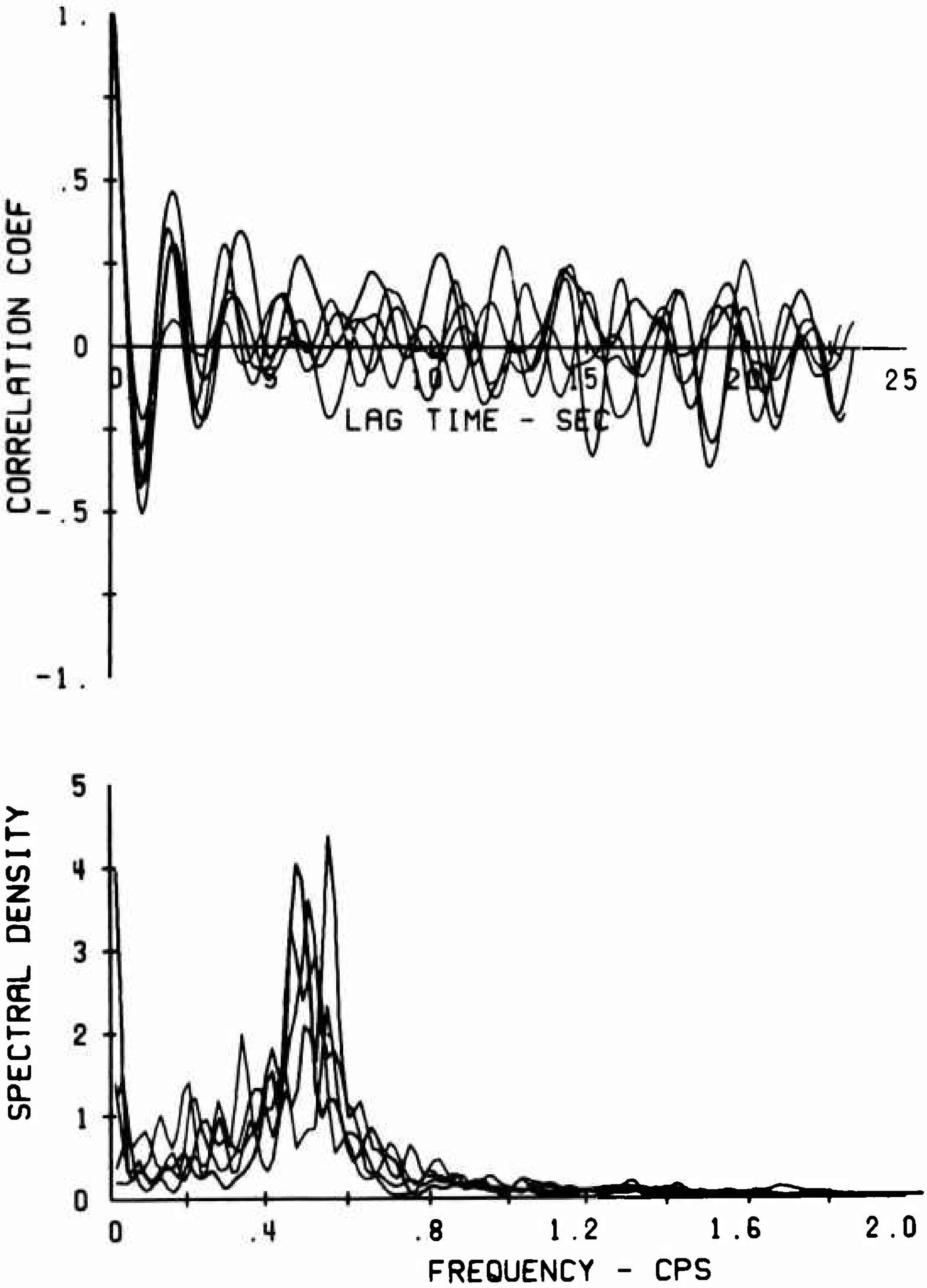
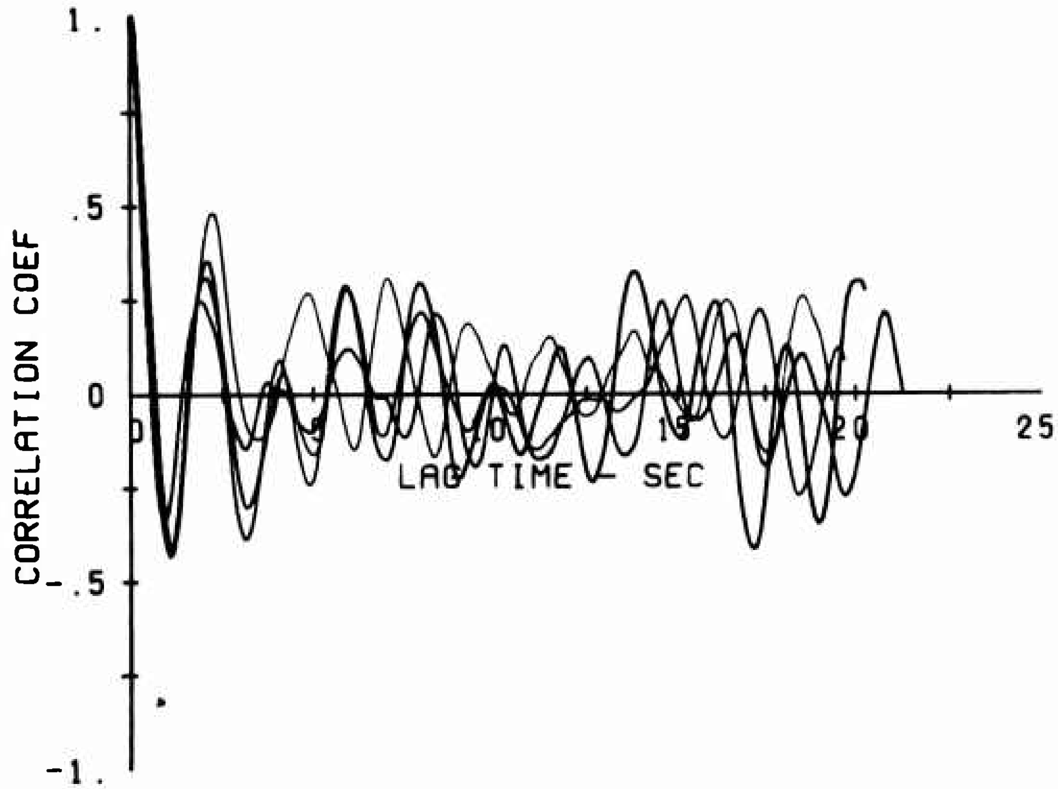


FIGURE 89. LATERAL STICK PSD, IGE HOVER, PILOT 2, WING AND TAIL OFF



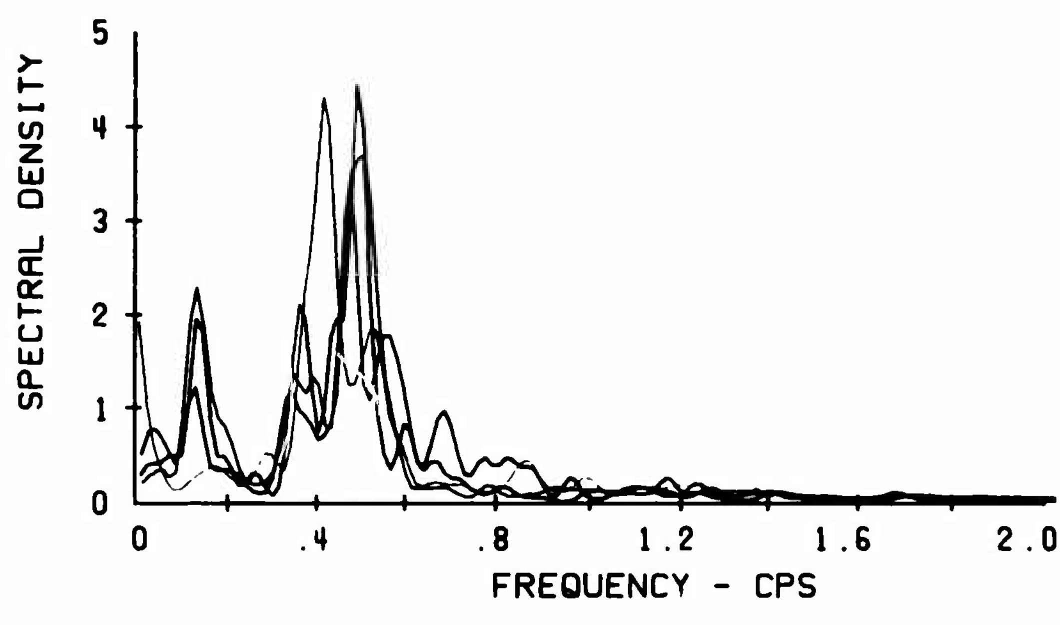


FIGURE 90. LATERAL STICK PSD, IGE HOVER, PILOT 3, WING AND TAIL ON

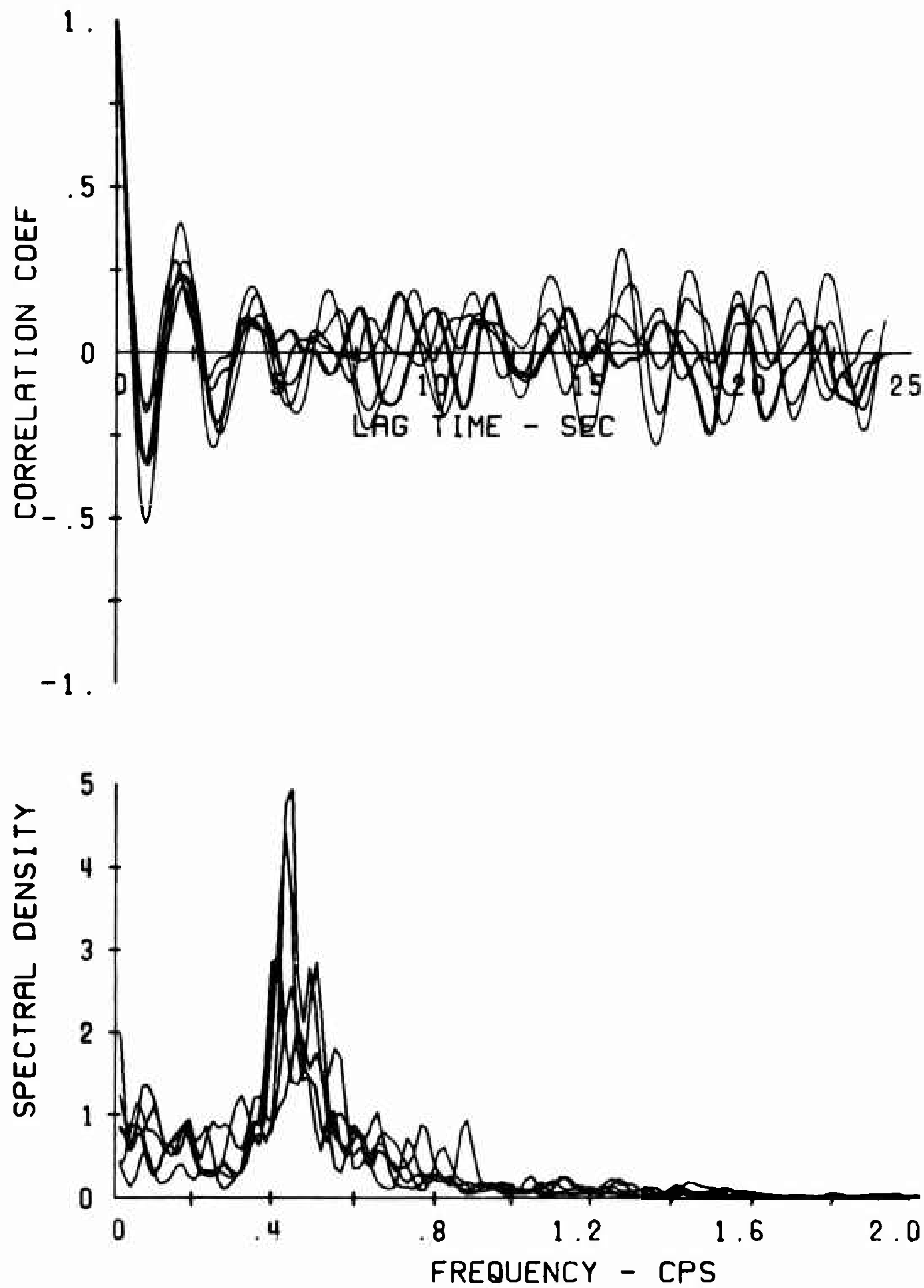


FIGURE 91. LATERAL STICK PSD, IGE HOVER, PILOT 3, WING AND TAIL OFF

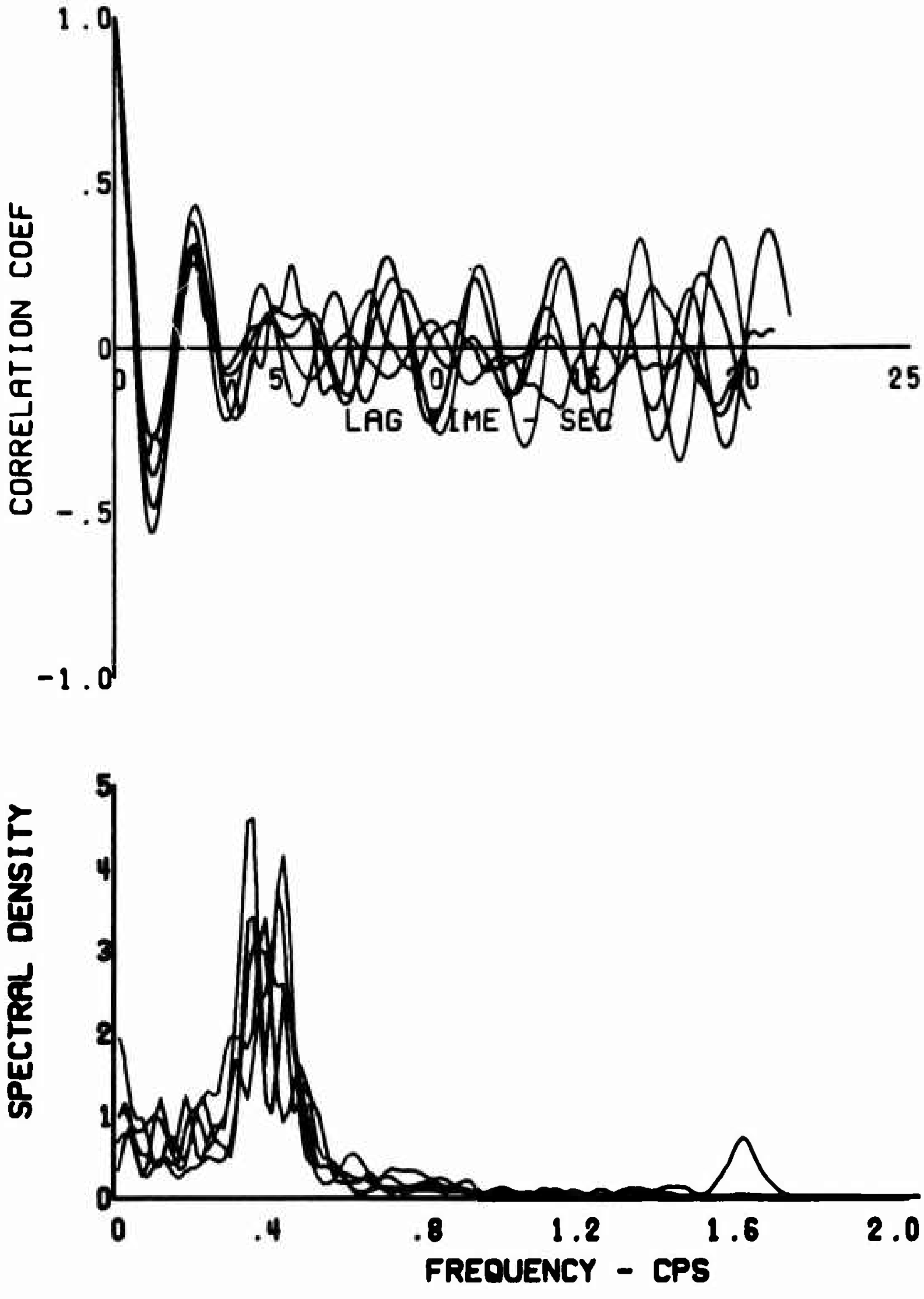


FIGURE 92. LATERAL STICK PSD, OGE HOVER, PILOT 1, WING AND TAIL ON

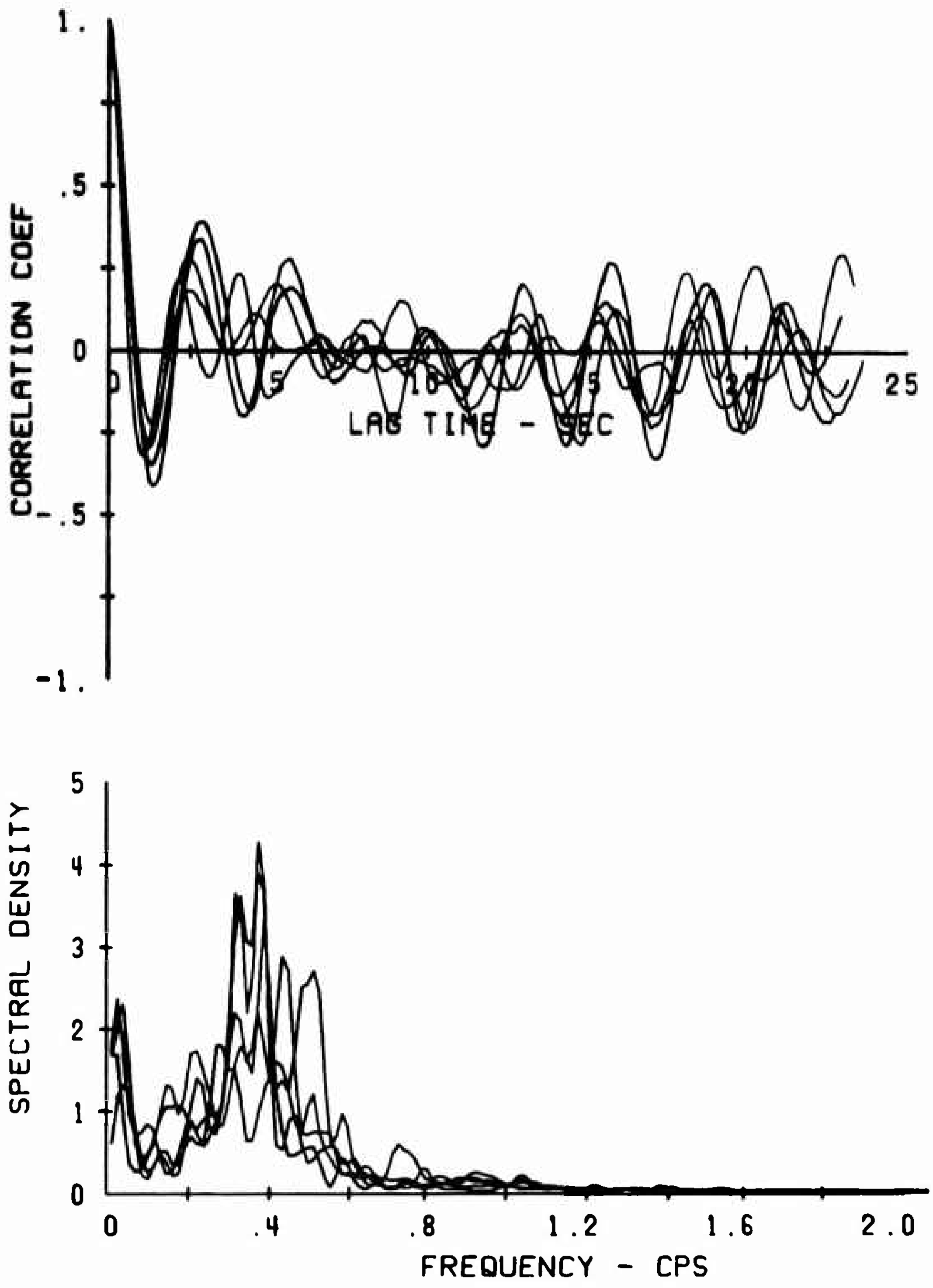


FIGURE 93. LATERAL STICK PSD, OGE HOVER, PILOT 1, WING AND TAIL OFF

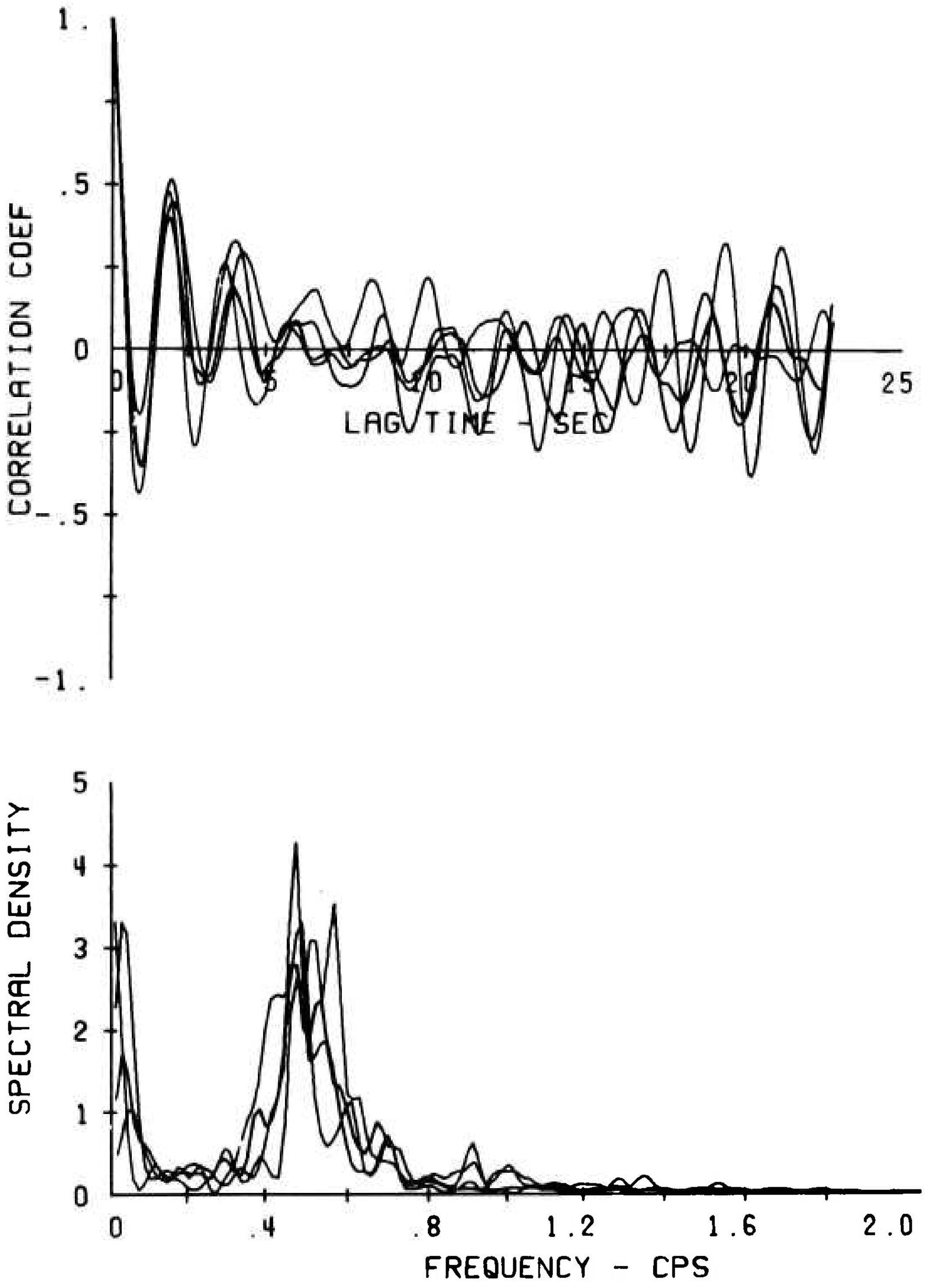


FIGURE 94. LATERAL STICK PSD, OGE HOVER, PILOT 2, WING AND TAIL ON·

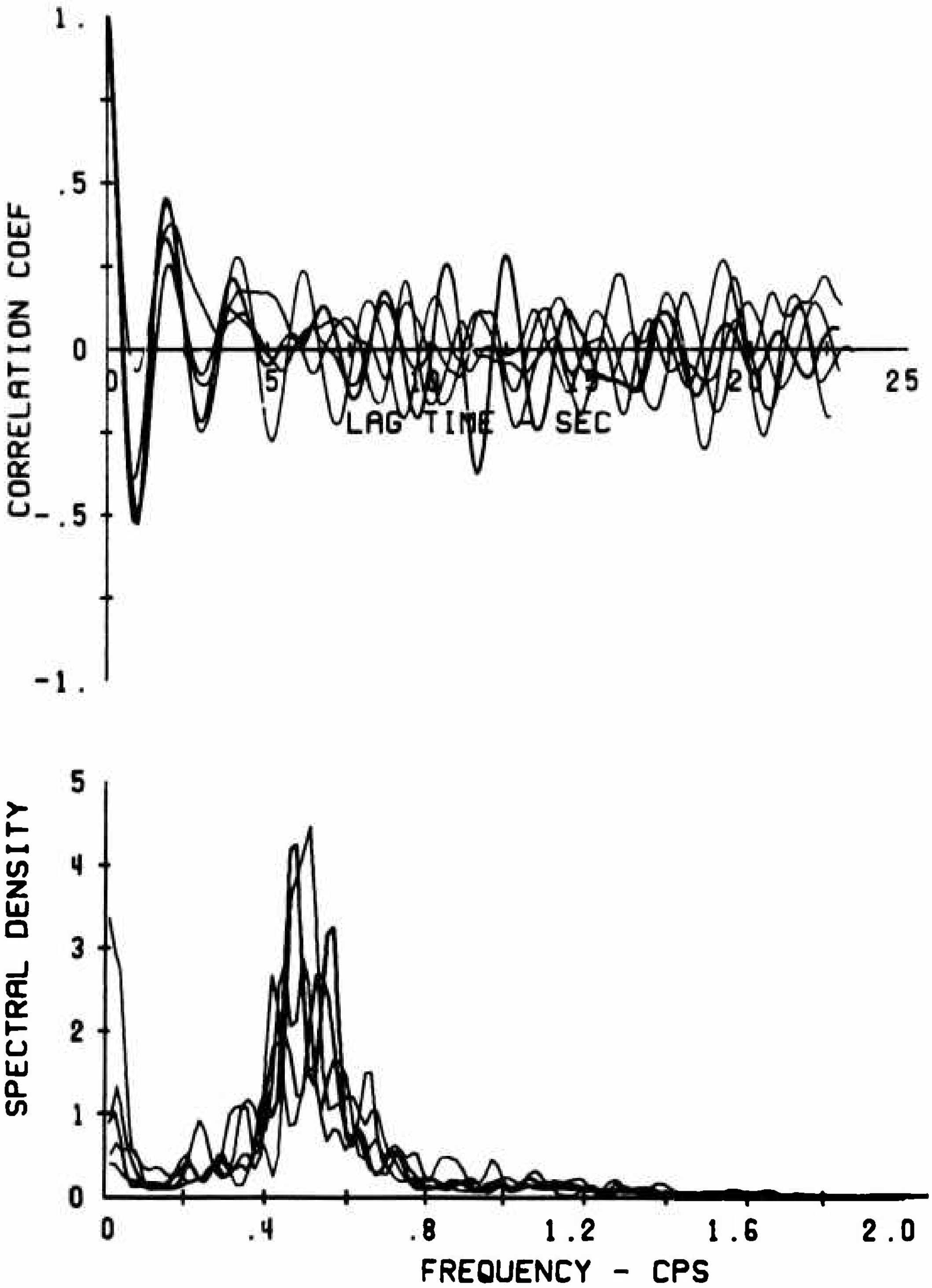


FIGURE 95. LATERAL STICK PSD, OGE HOVER, PILOT 2, WING AND TAIL OFF

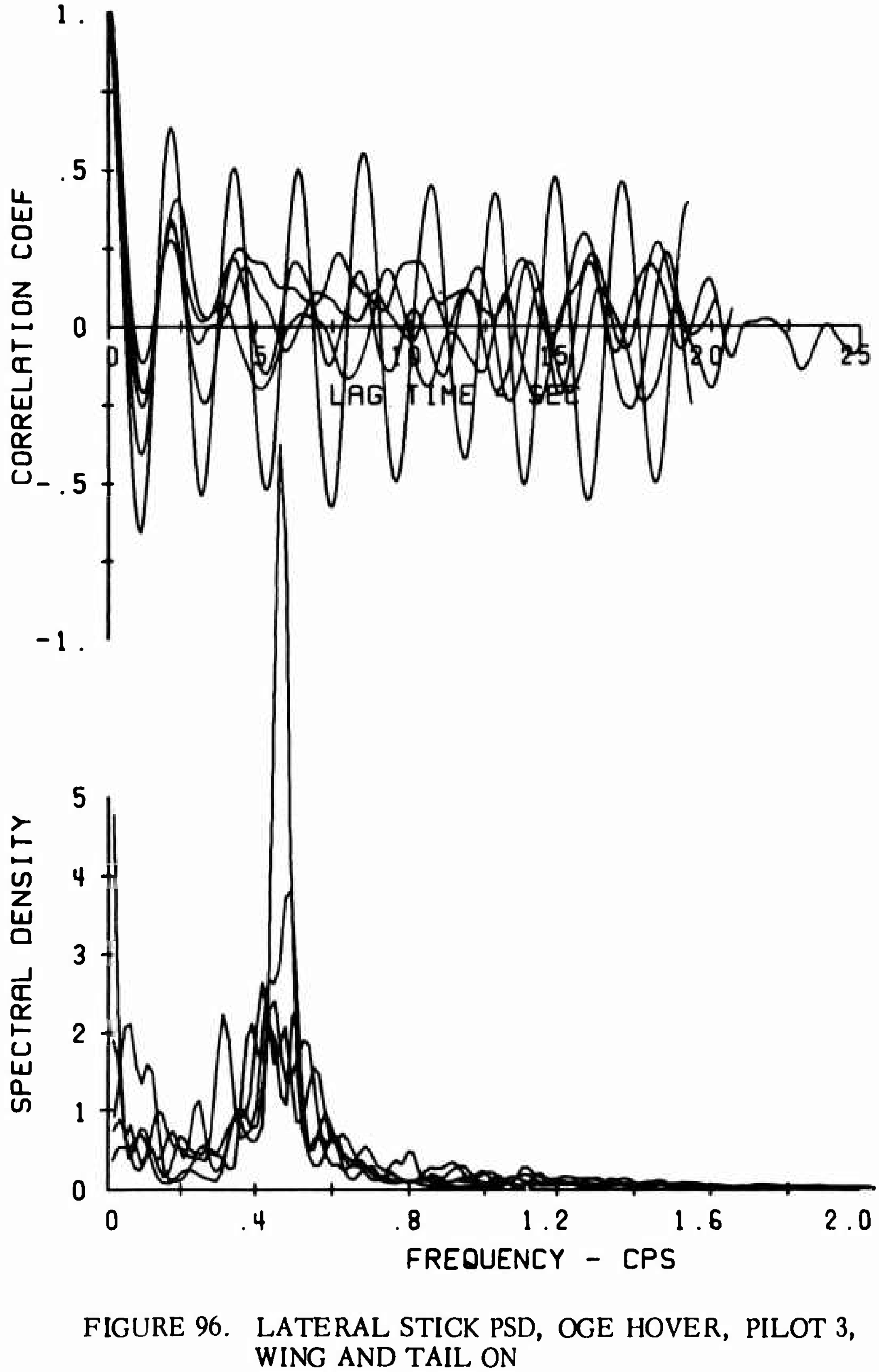


FIGURE 96. LATERAL STICK PSD, OGE HOVER, PILOT 3, WING AND TAIL ON

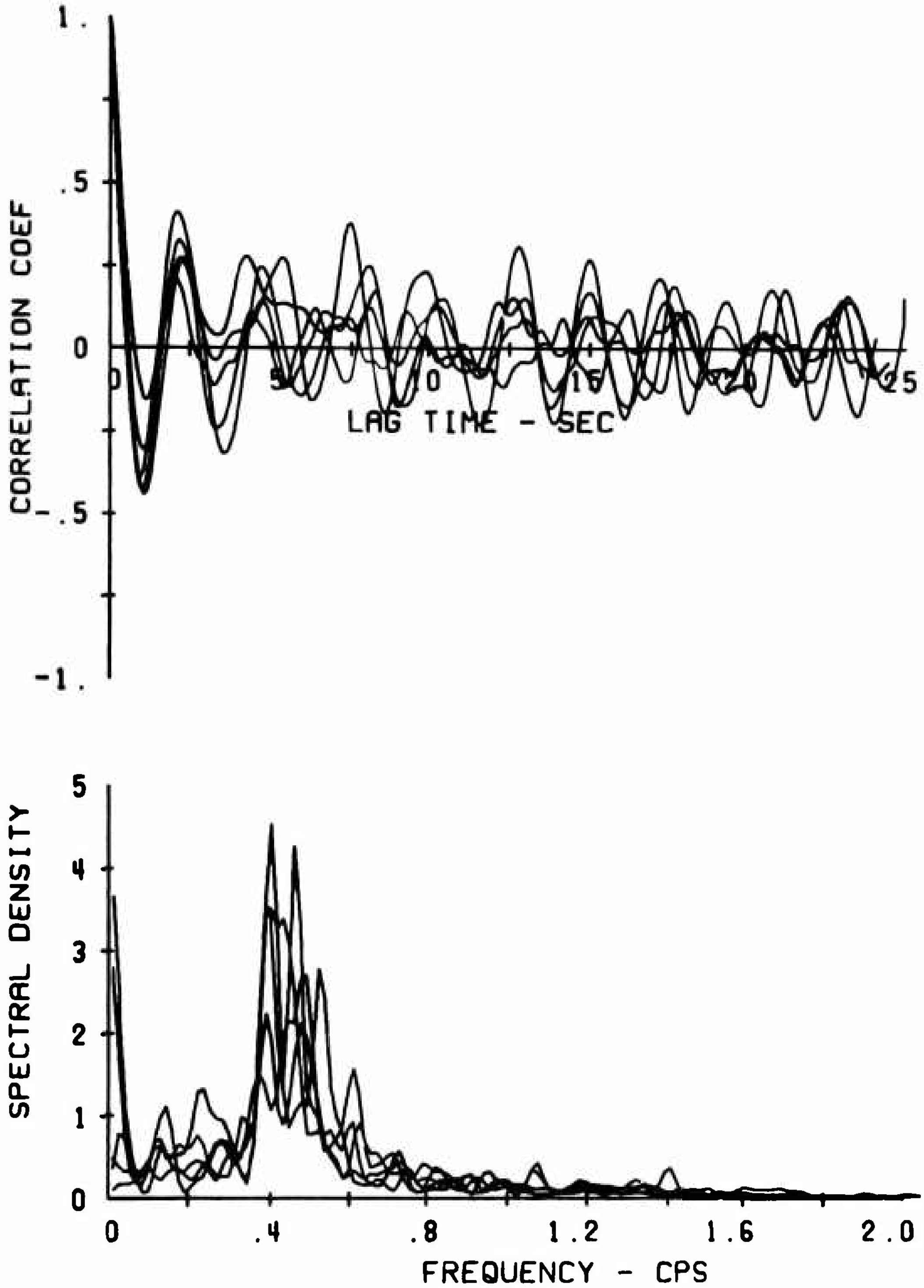


FIGURE 97. LATERAL STICK PSD, OGE HOVER, PILOT 3, WING AND TAIL OFF

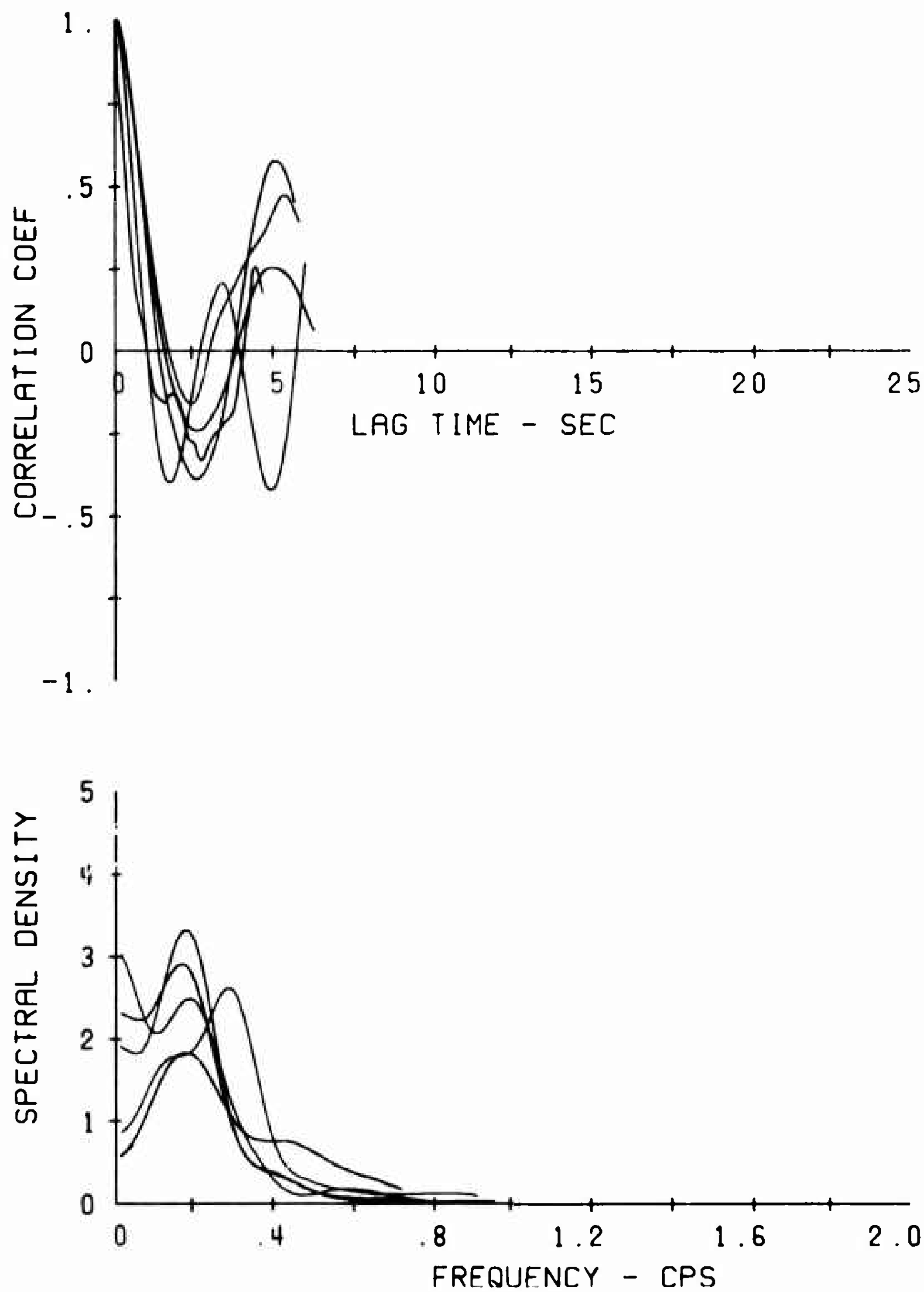


FIGURE 98. LONGITUDINAL STICK PSD, RIGHT HOVER TURN, PILOT 1, WING AND TAIL ON

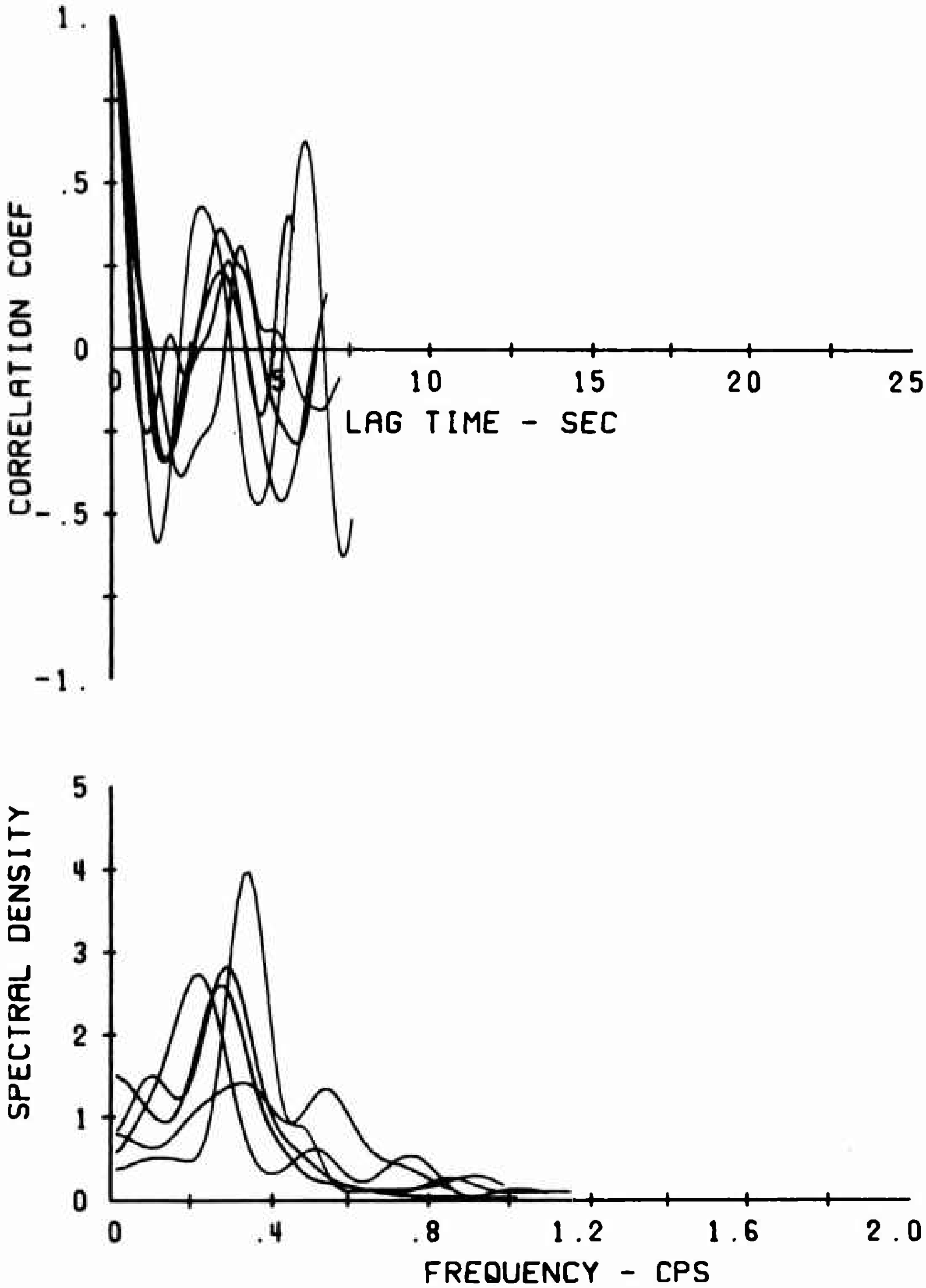


FIGURE 99. LONGITUDINAL STICK PSD, RIGHT HOVER TURN, PILOT 1, WING AND TAIL OFF

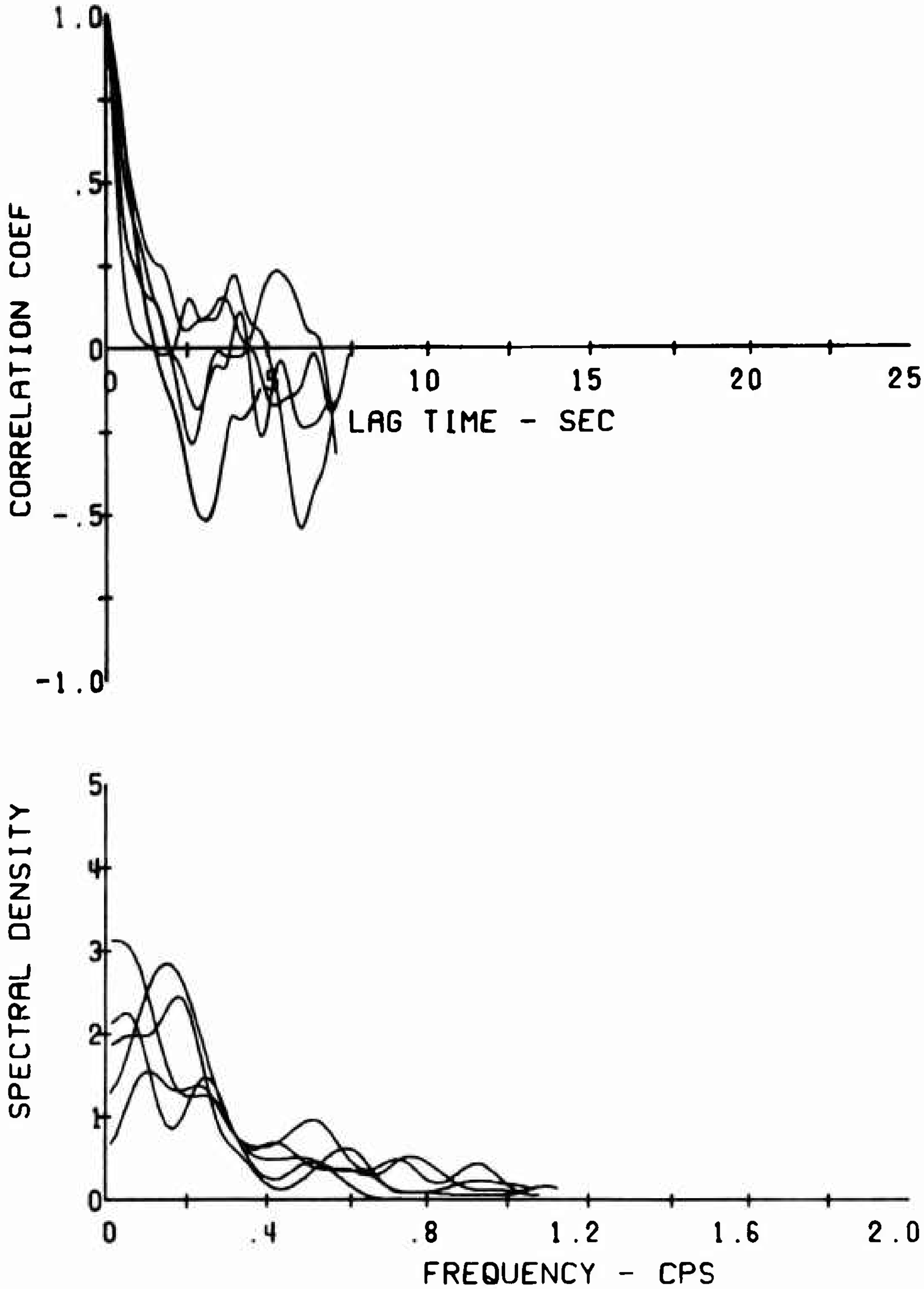


FIGURE 100. LONGITUDINAL STICK PSD, RIGHT HOVER TURN, PILOT 2, WING AND TAIL ON

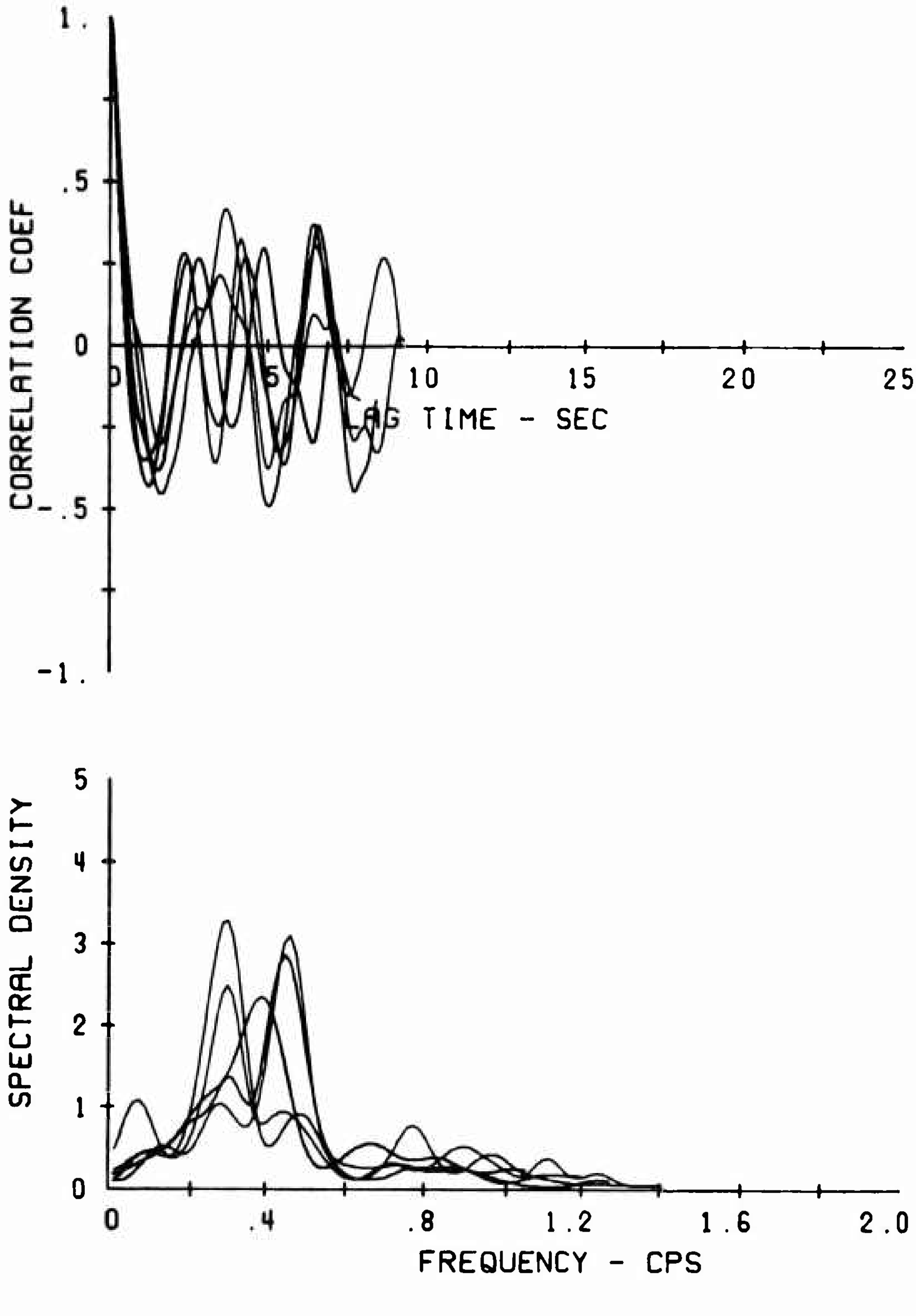
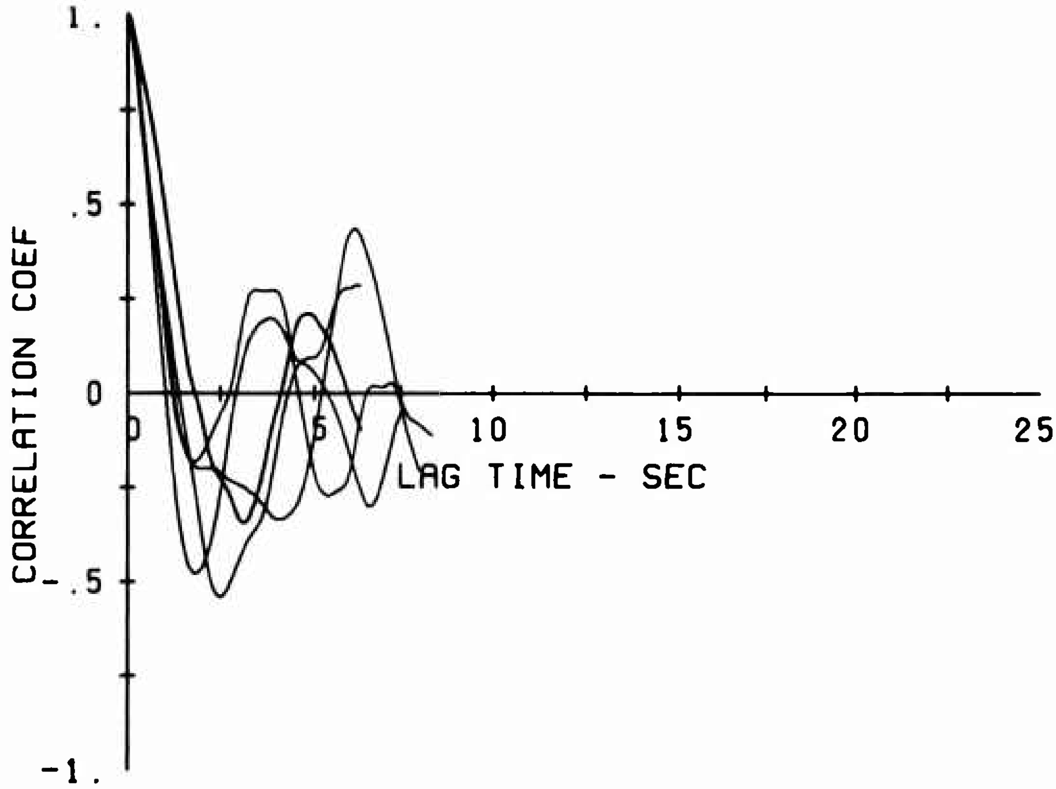


FIGURE 101. LONGITUDINAL STICK PSD, RIGHT HOVER TURN, PILOT 2, WING AND TAIL OFF



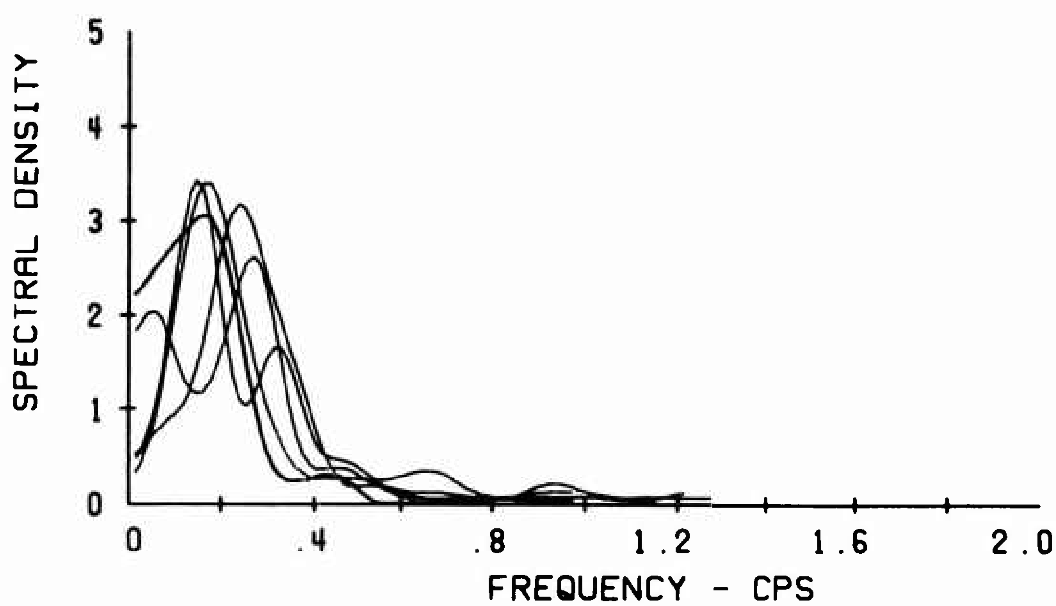


FIGURE 102. LONGITUDINAL STICK PSD, RIGHT HOVER TURN, PILOT 3, WING AND TAIL ON

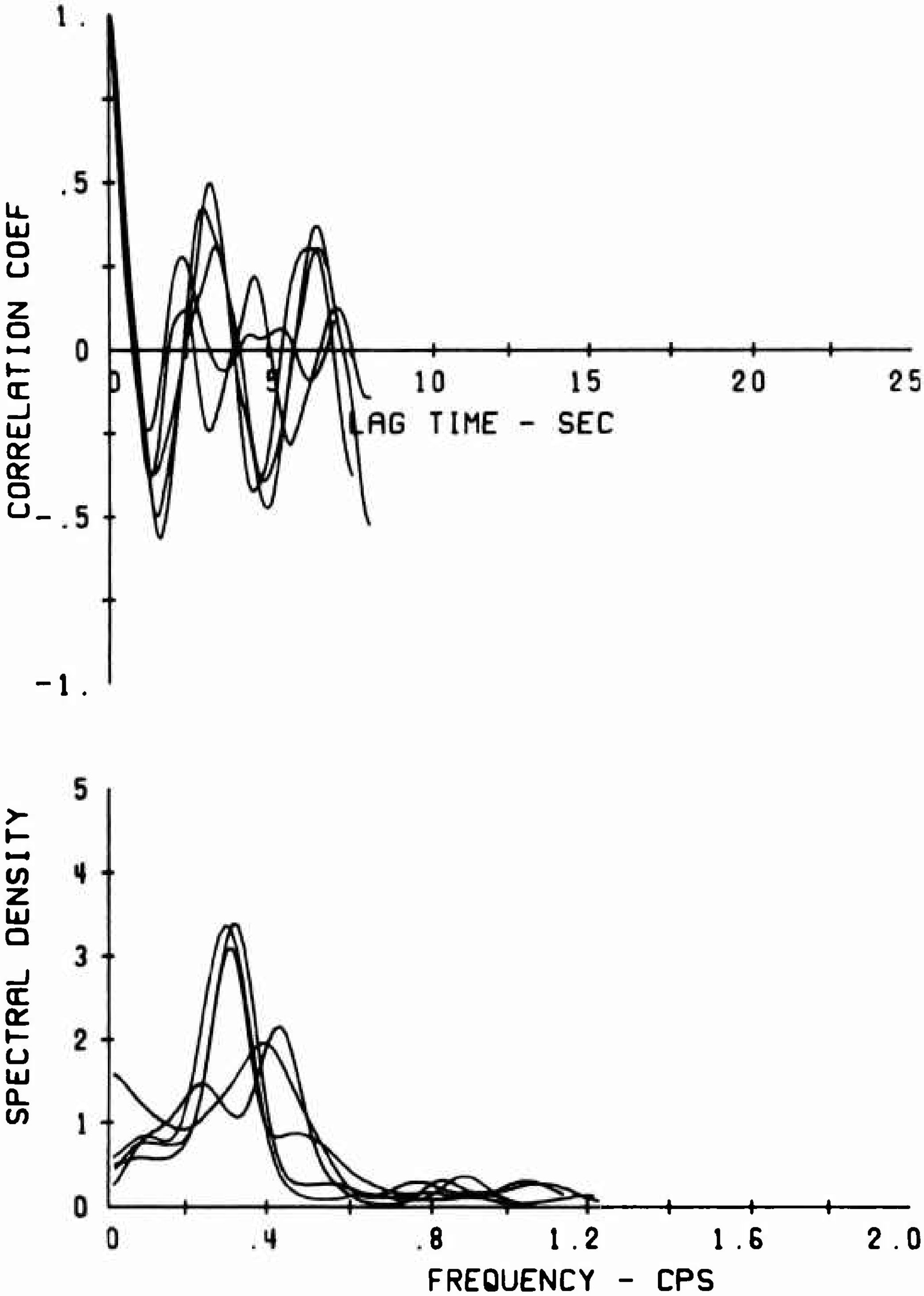


FIGURE 103. LONGITUDINAL STICK PSD, RIGHT HOVER TURN, PILOT 3, WING AND TAIL OFF

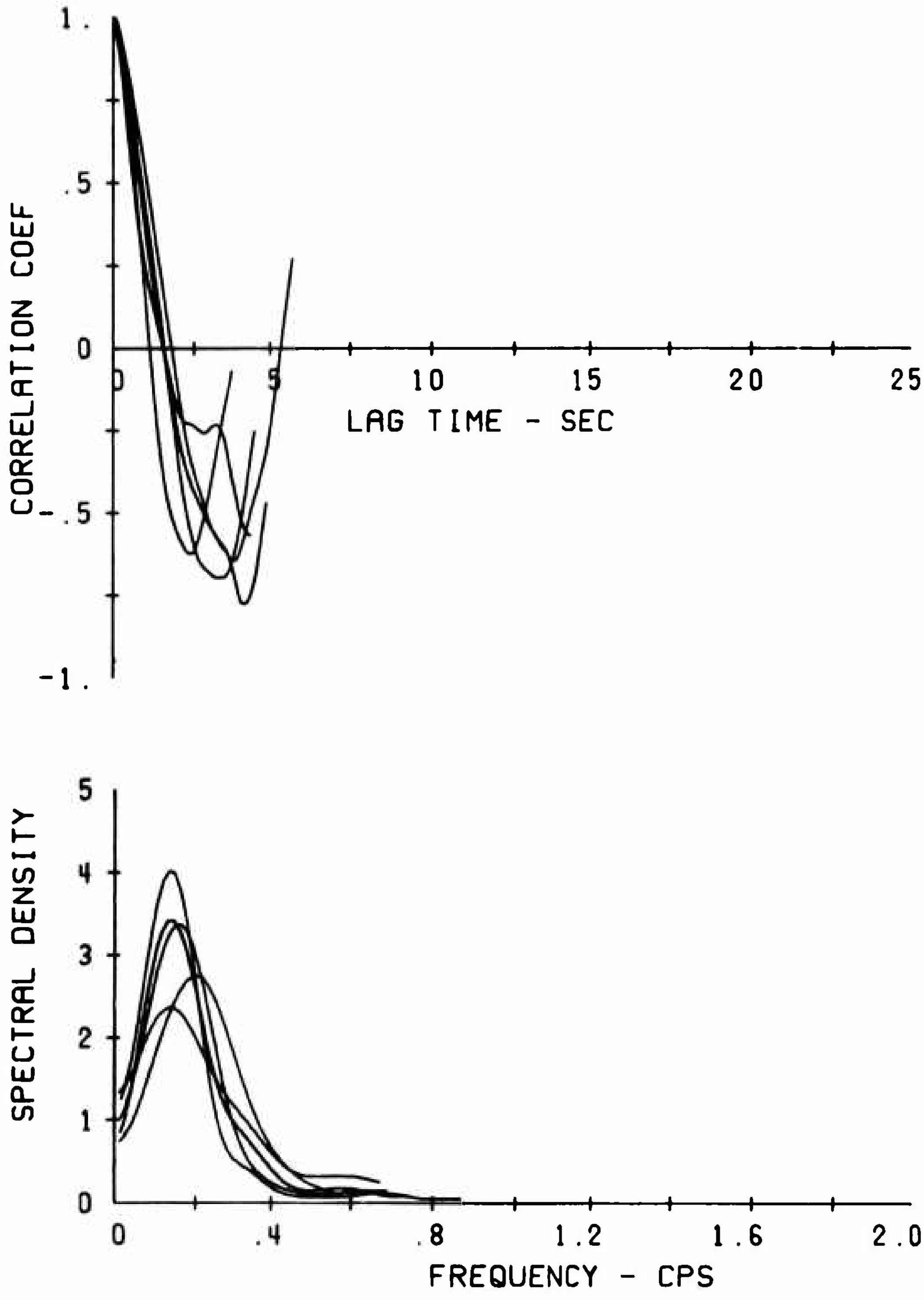


FIGURE 104. LONGITUDINAL STICK PSD, LEFT AIR TAXI, PILOT 1, WING AND TAIL ON

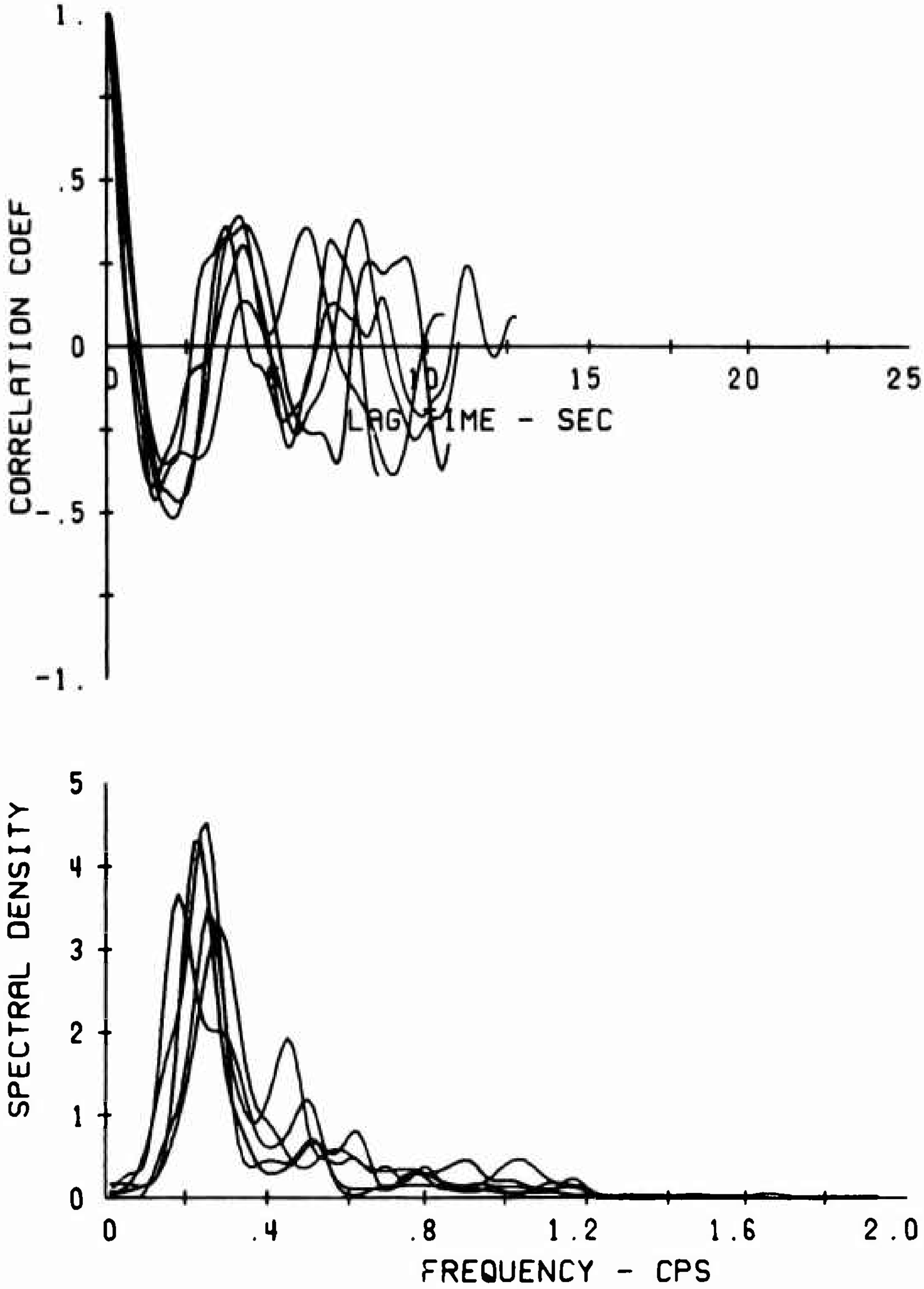


FIGURE 105. LONGITUDINAL STICK PSD, LEFT AIR TAXI, PILOT 1, WING AND TAIL OFF

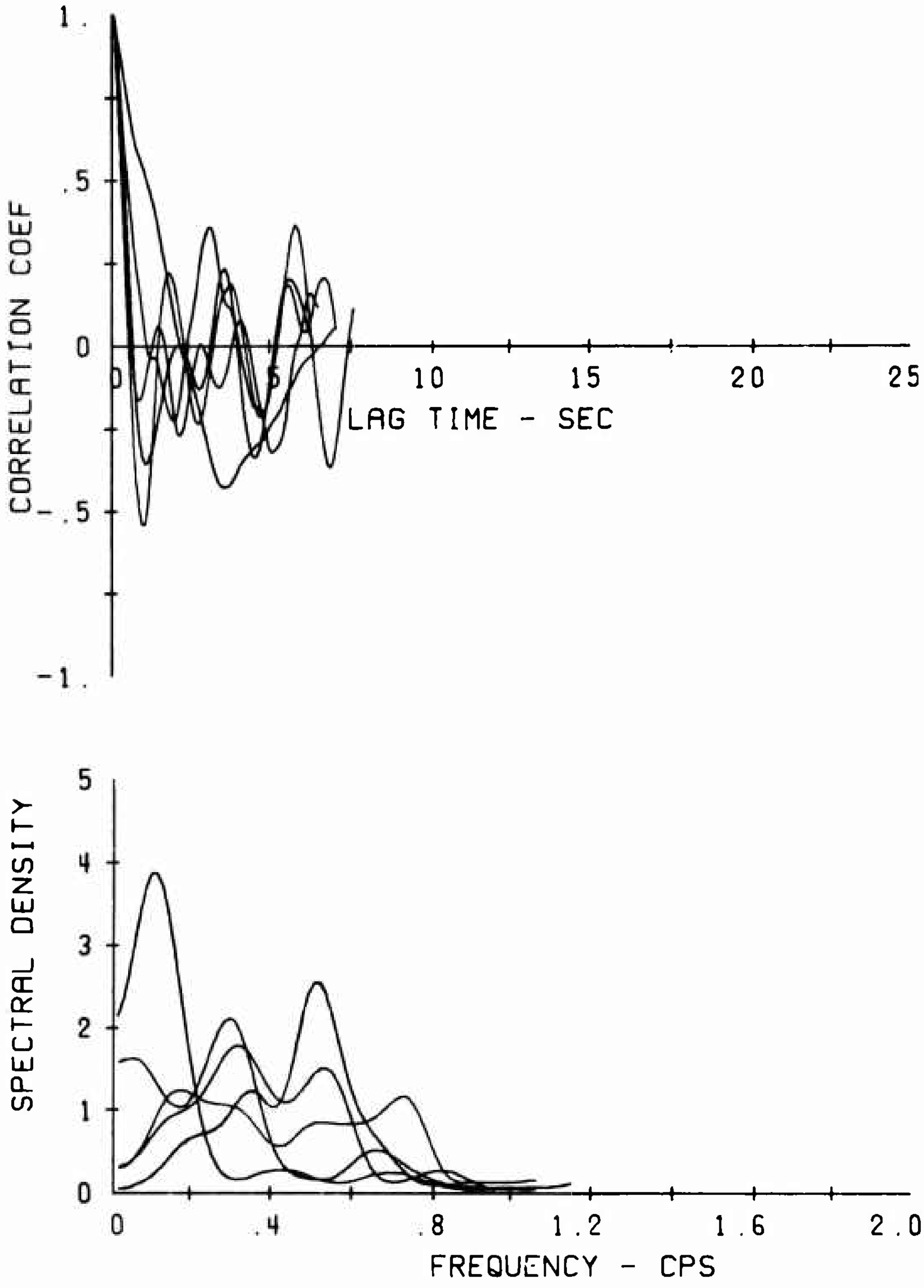
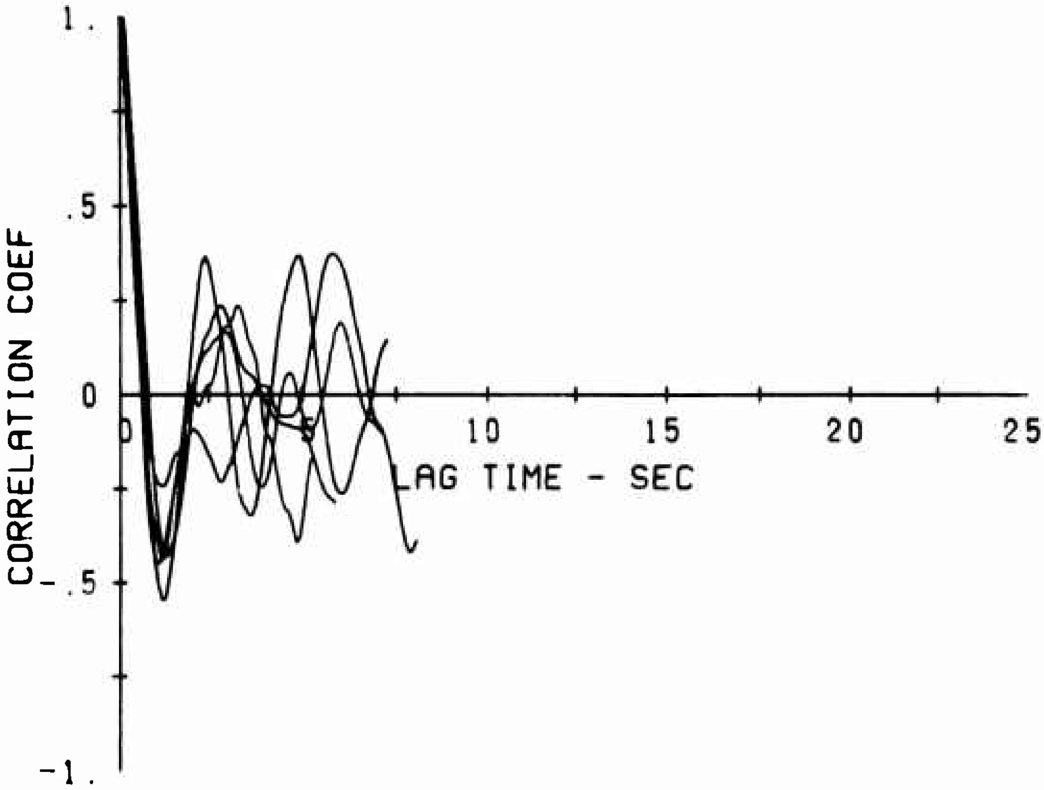


FIGURE 106. LONGITUDINAL STICK PSD, LEFT AIR TAXI, PILOT 2, WING AND TAIL ON



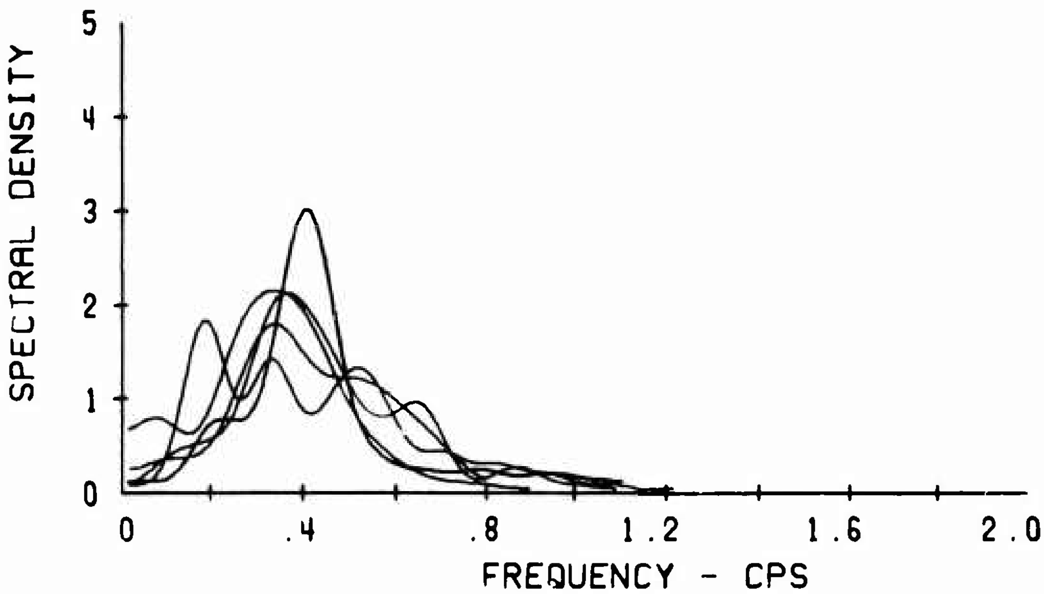


FIGURE 107. LONGITUDINAL STICK PSD, LEFT AIR TAXI, PILOT 2, WING AND TAIL OFF

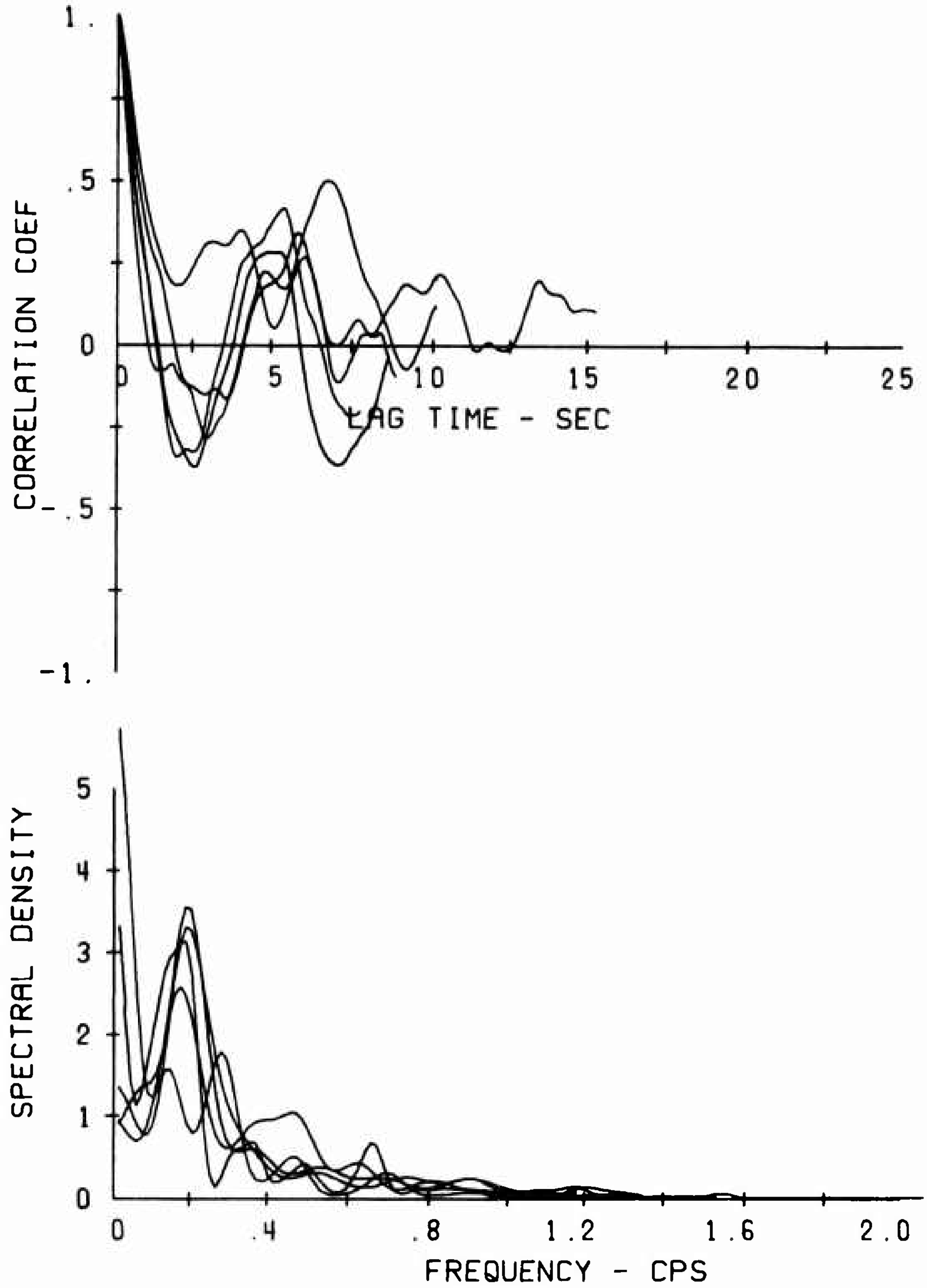


FIGURE 108. LONGITUDINAL STICK PSD, LEFT AIR TAXI, PILOT 3, WING AND TAIL ON

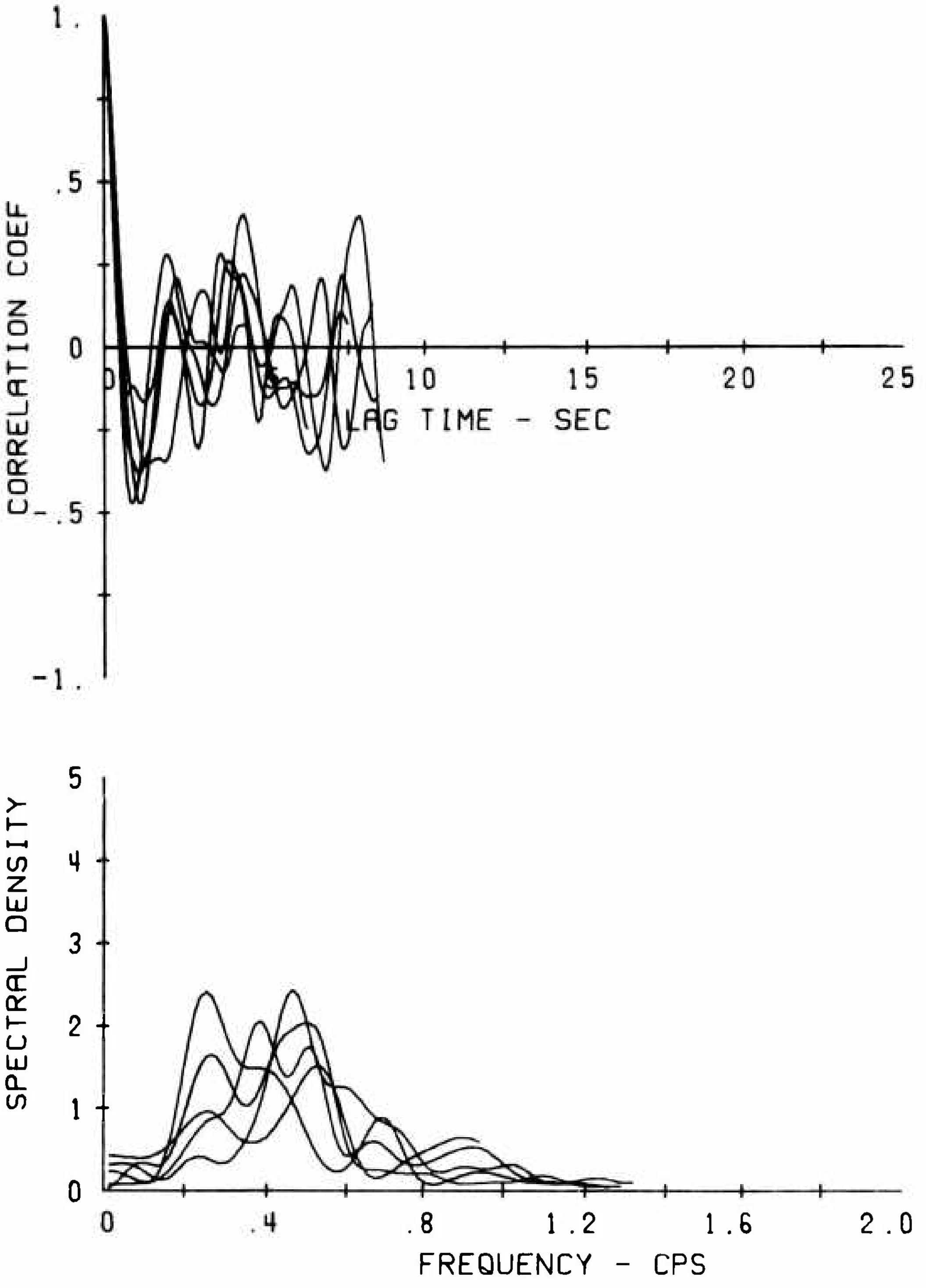


FIGURE 109. LONGITUDINAL STICK PSD, LEFT AIR TAXI, PILOT 3, WING AND TAIL OFF

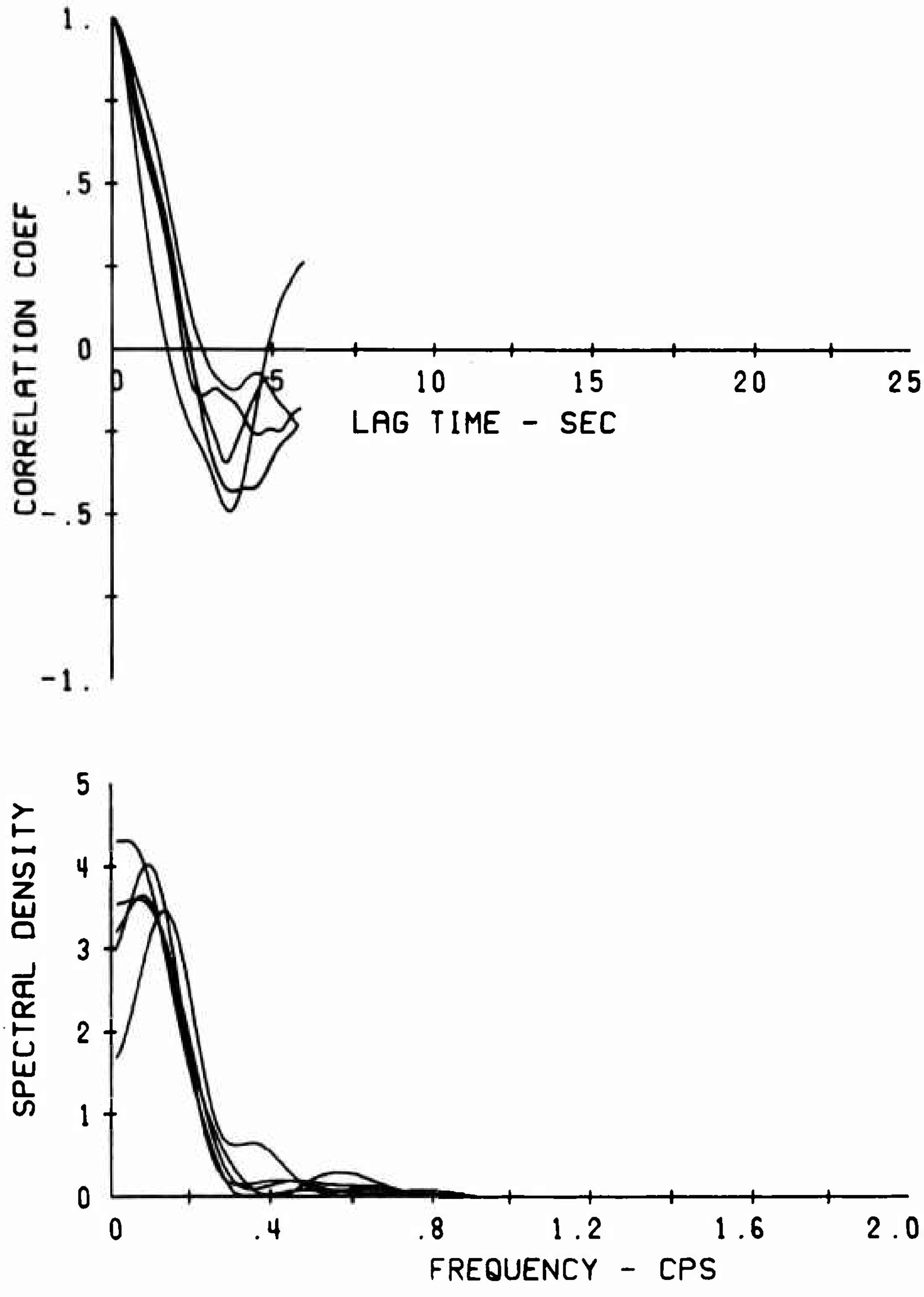


FIGURE 110. LONGITUDINAL STICK PSD, FORWARD AIR TAXI, PILOT 1, WING AND TAIL ON

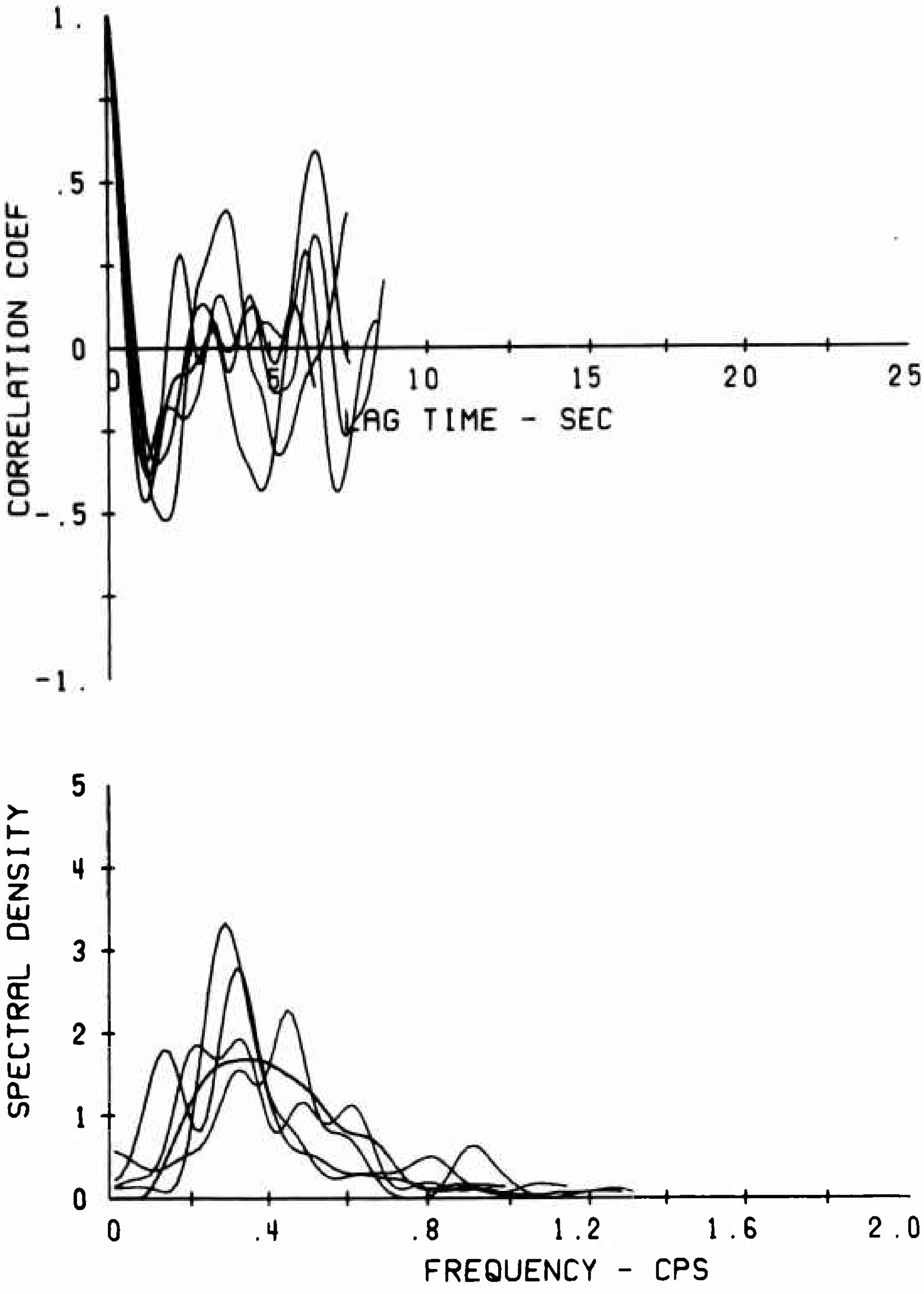


FIGURE 111. LONGITUDINAL STICK PSD, FORWARD AIR TAXI, PILOT 1, WING AND TAIL OFF

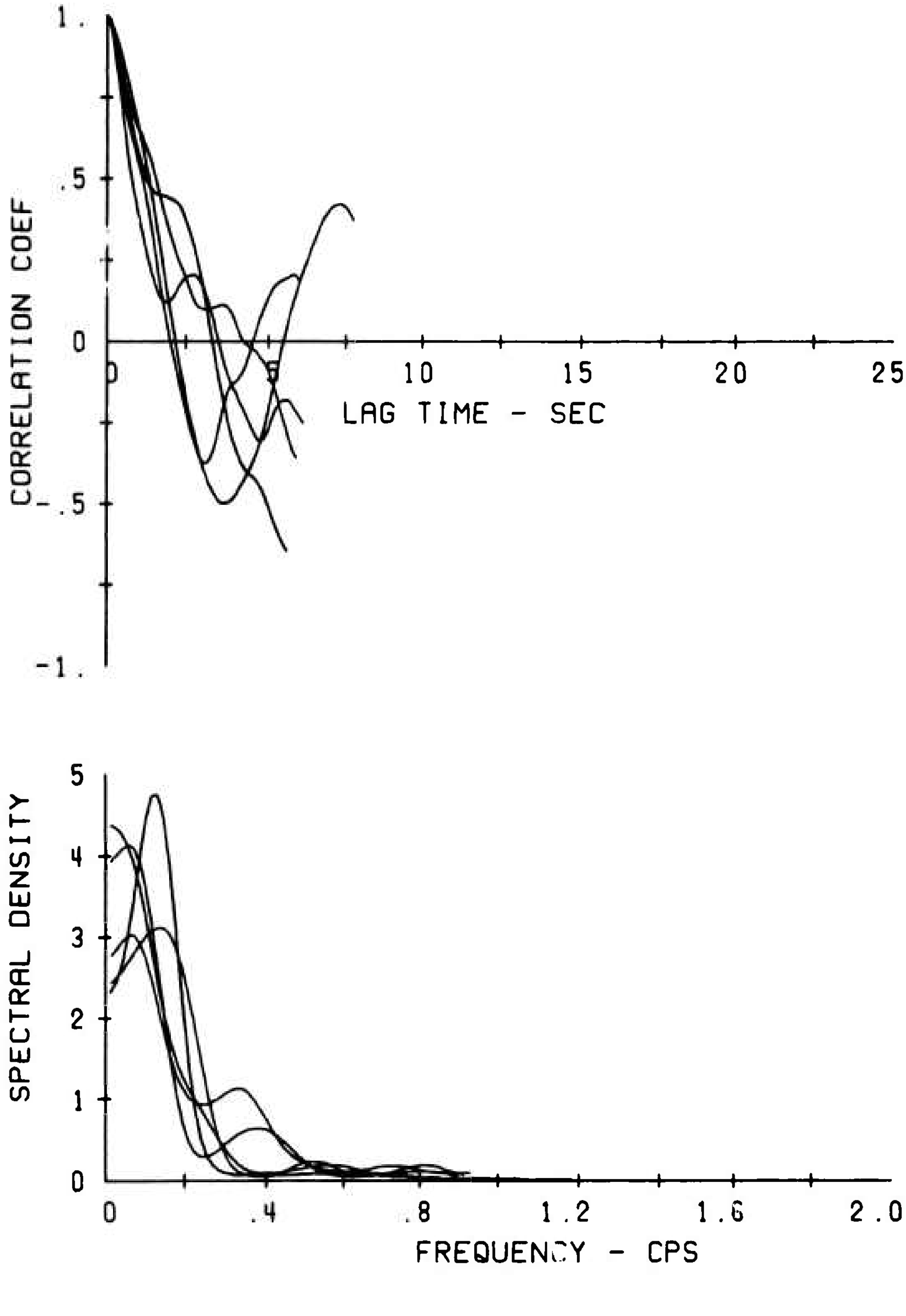


FIGURE 112. LONGITUDINAL STICK PSD, FORWARD AIR TAXI, PILOT 2, WING AND TAIL ON

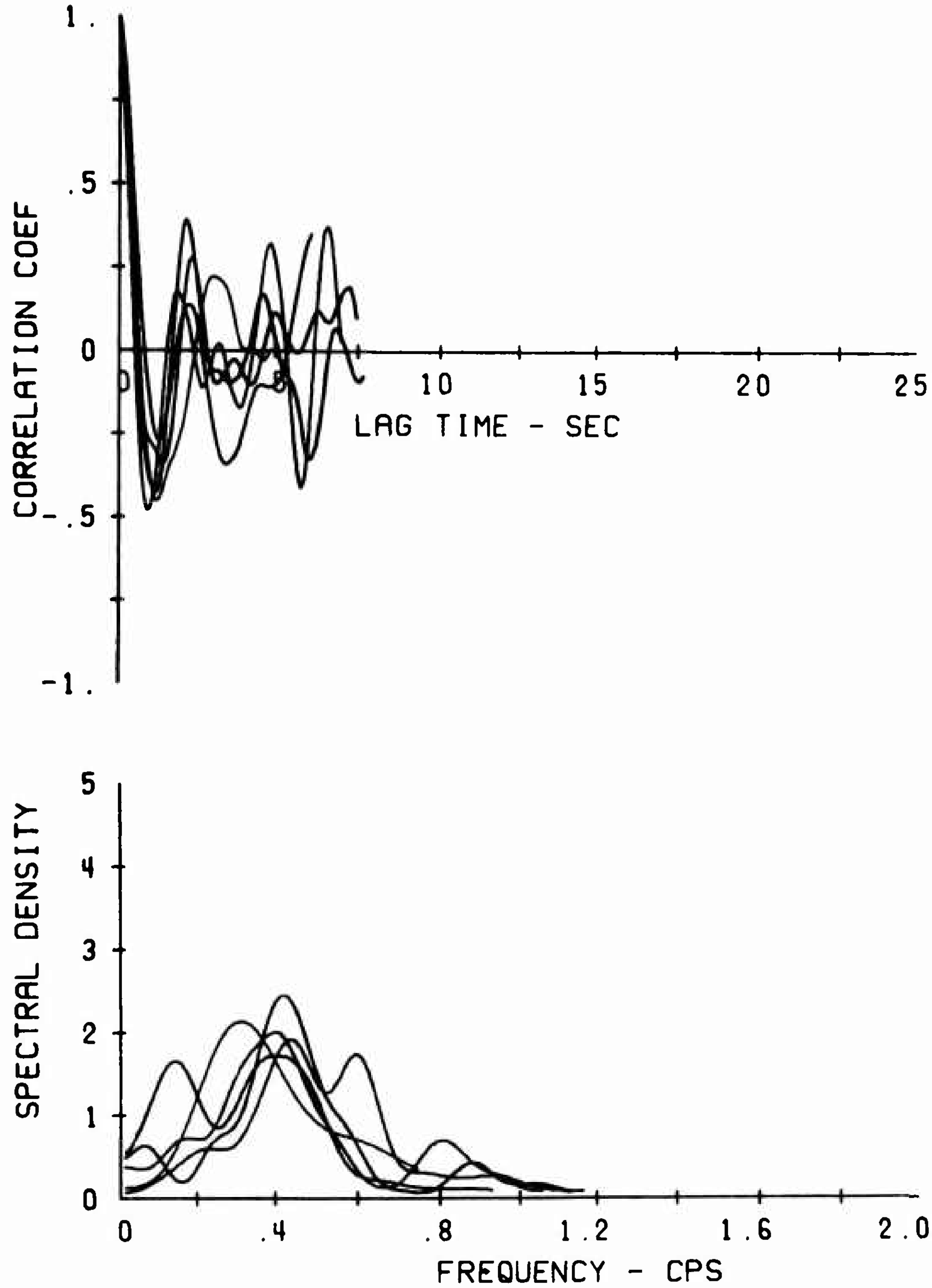


FIGURE 113. LONGITUDINAL STICK PSD, FORWARD AIR TAXI, PILOT 2, WING AND TAIL OFF

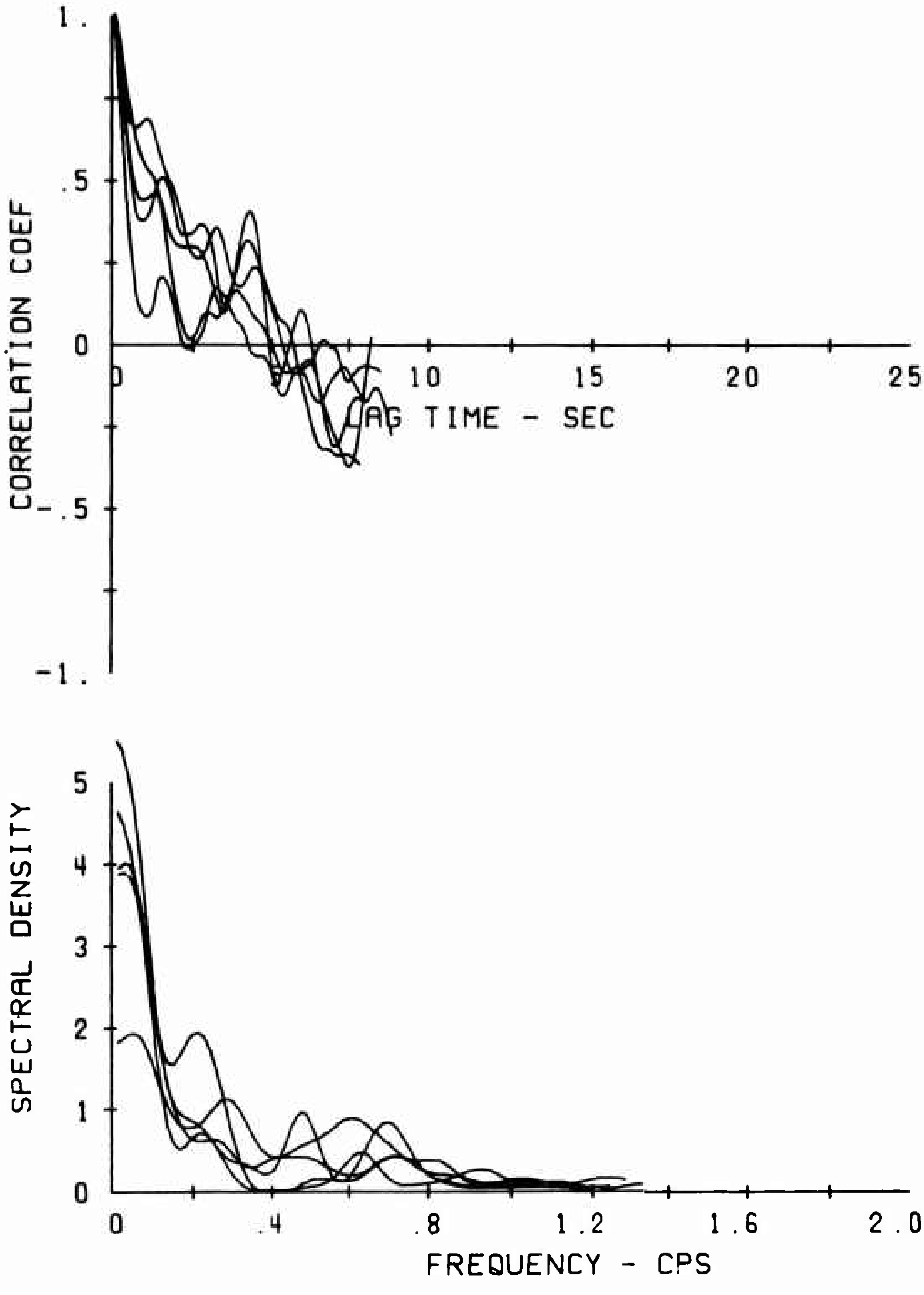
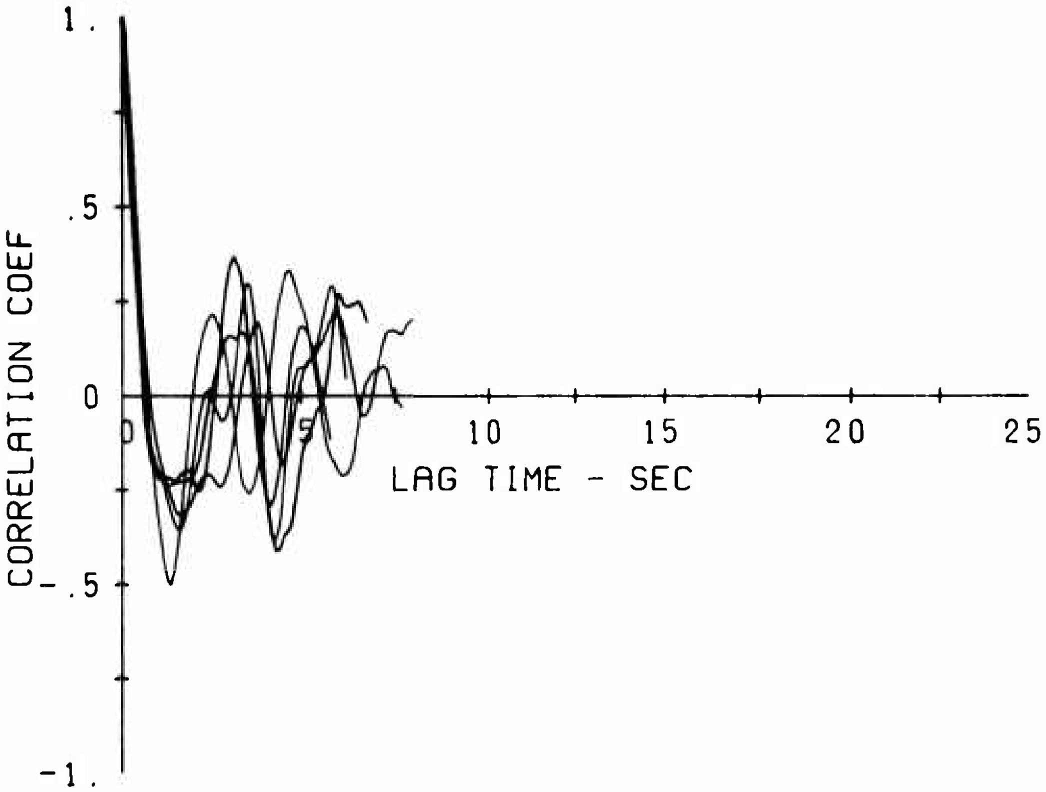


FIGURE 114. LONGITUDINAL STICK PSD, FORWARD AIR TAXI, PILOT 3, WING AND TAIL ON



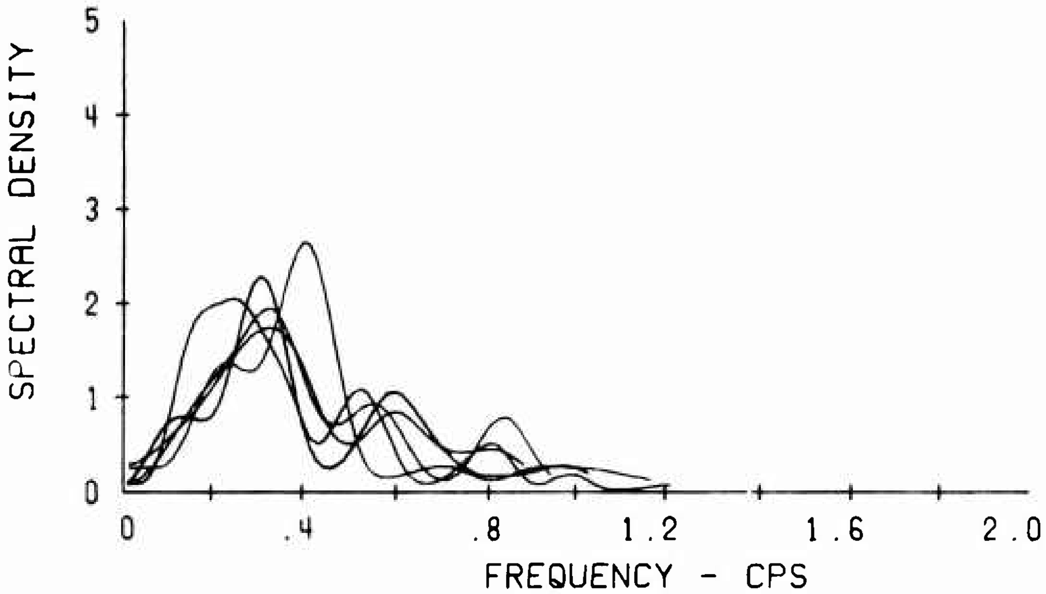


FIGURE 115. LONGITUDINAL STICK PSD, FORWARD AIR TAXI, PILOT 3, WING AND TAIL OFF

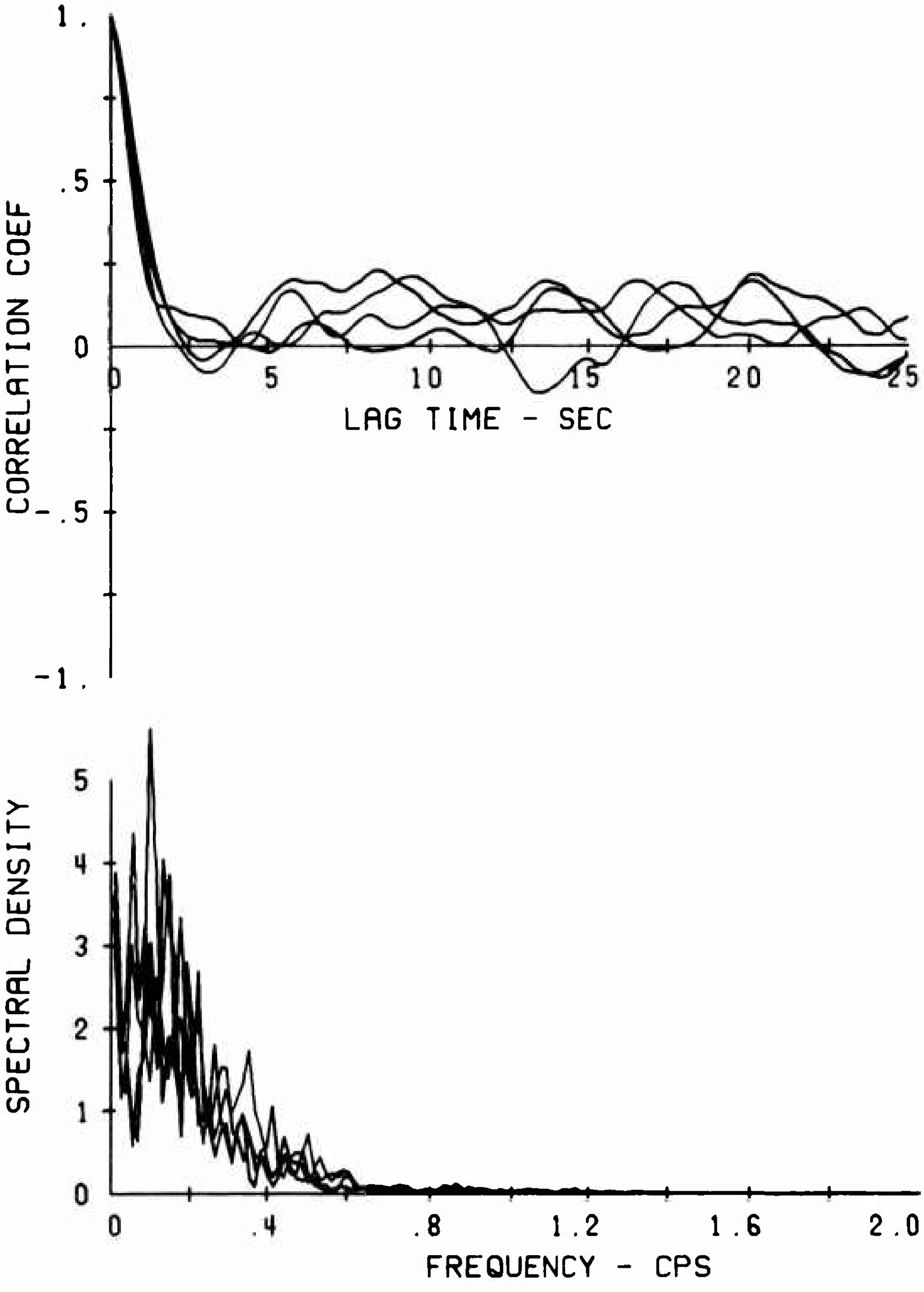


FIGURE 116. LONGITUDINAL STICK PSD, FIGURE "8" TURN,
PILOT 1, WING AND TAIL ON

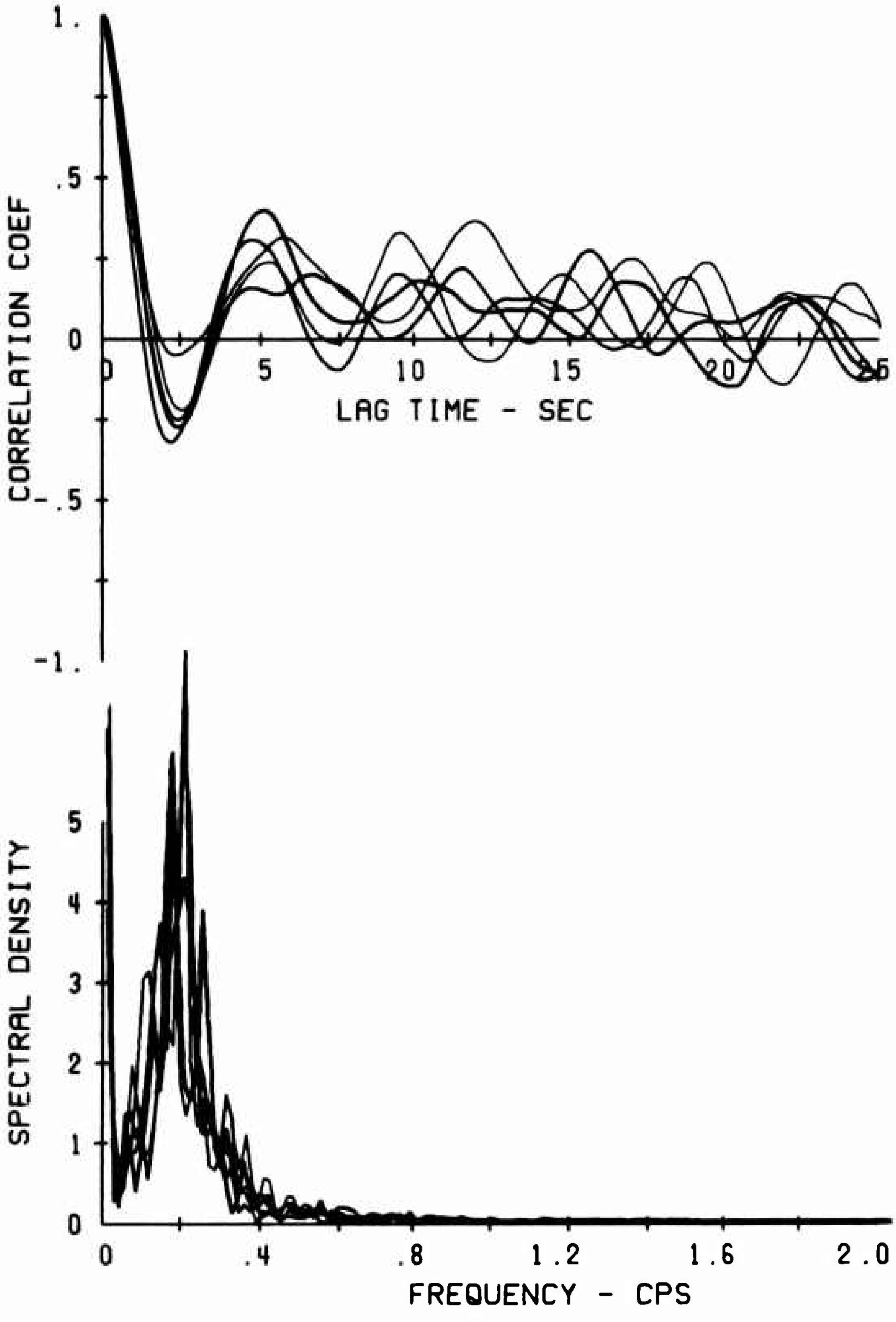


FIGURE 117. LONGITUDINAL STICK PSD, FIGURE "8" TURN, PILOT 1, WING AND TAIL OFF

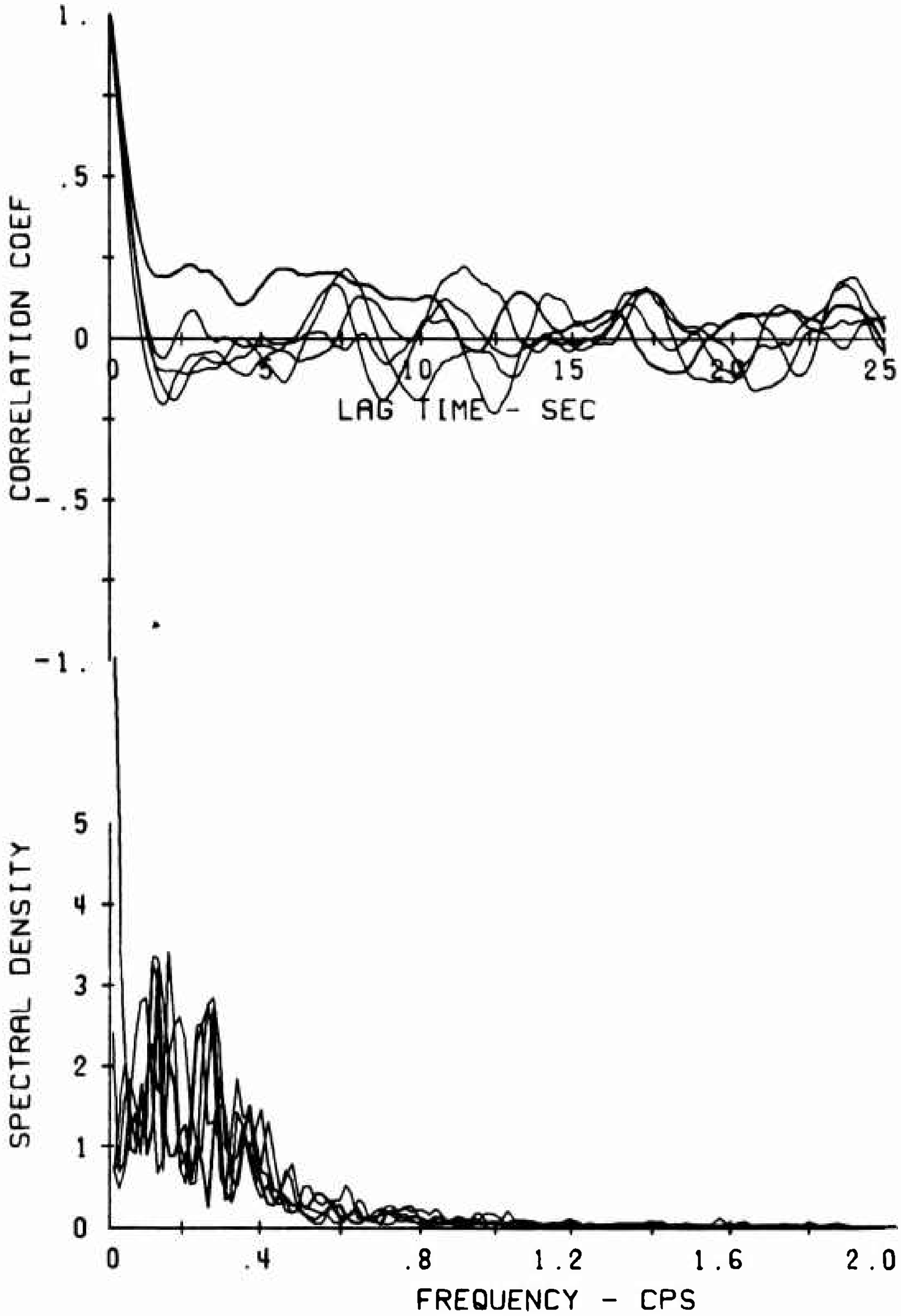


FIGURE 118. LONGITUDINAL STICK PSD, FIGURE "8" TURN, PILOT 2, WING AND TAIL ON

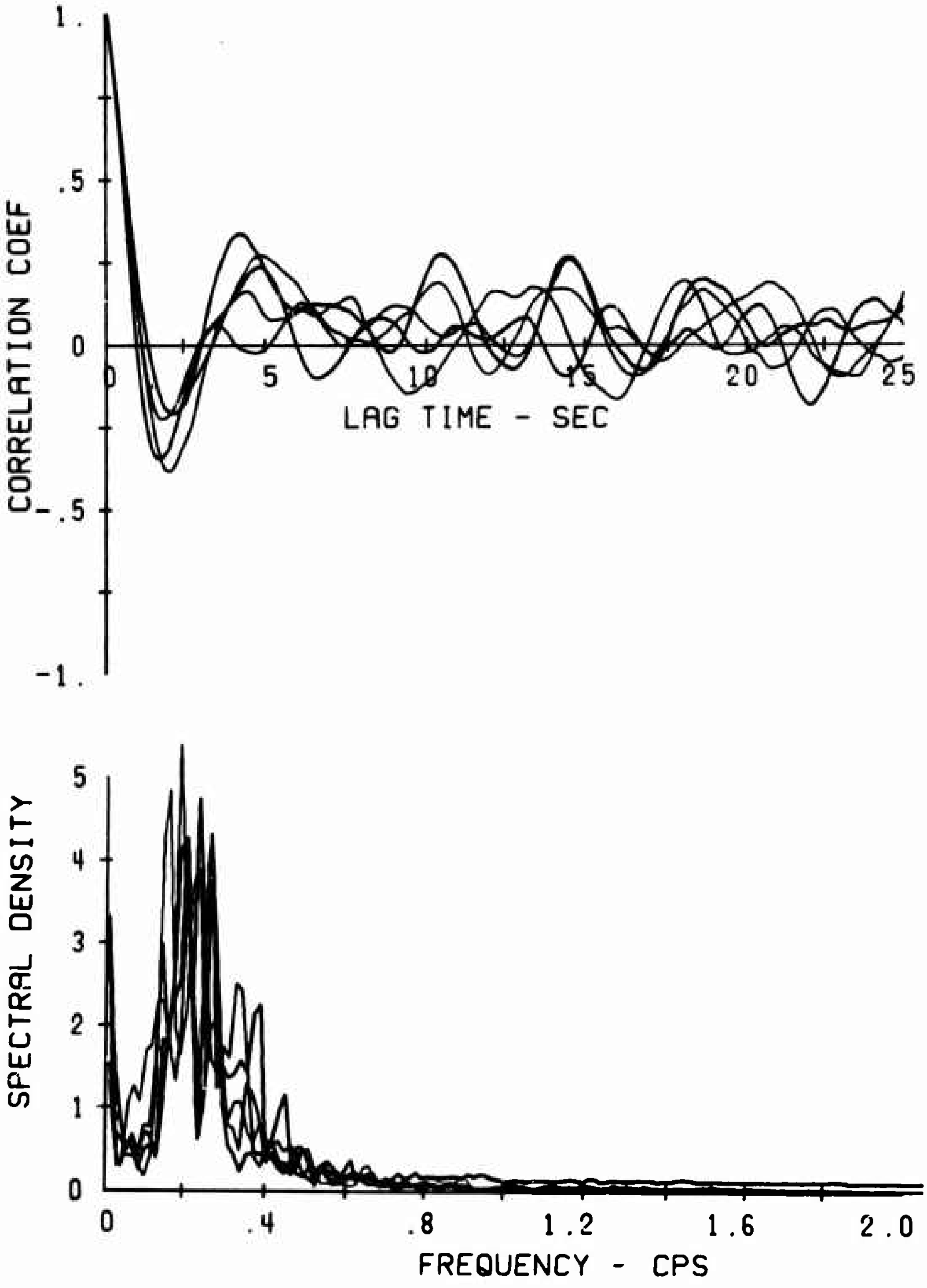


FIGURE 119. LONGITUDINAL STICK PSD, FIGURE "8" TURN, PILOT 2, WING AND TAIL OFF

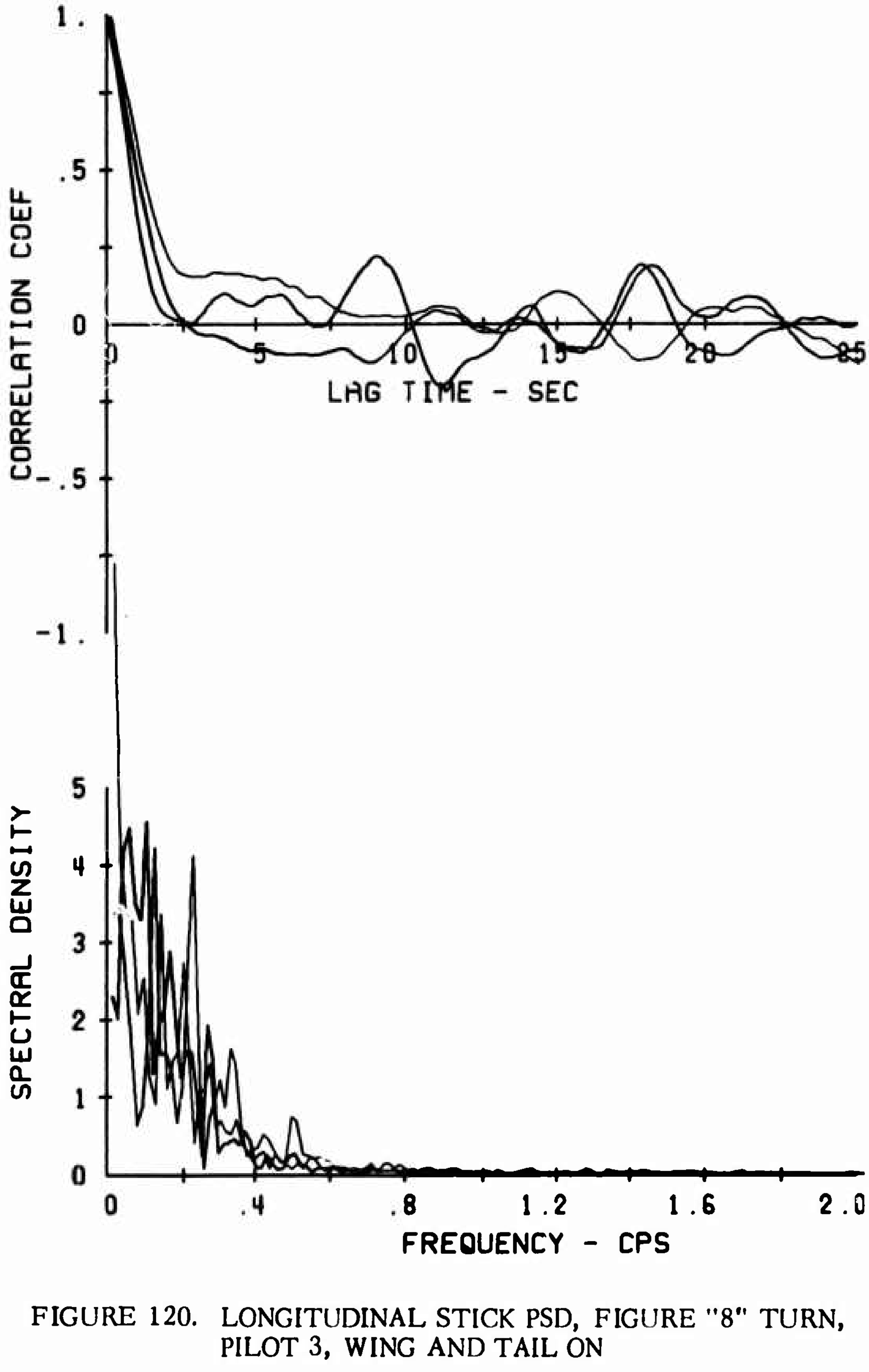


FIGURE 120. LONGITUDINAL STICK PSD, FIGURE "8" TURN, PILOT 3, WING AND TAIL ON

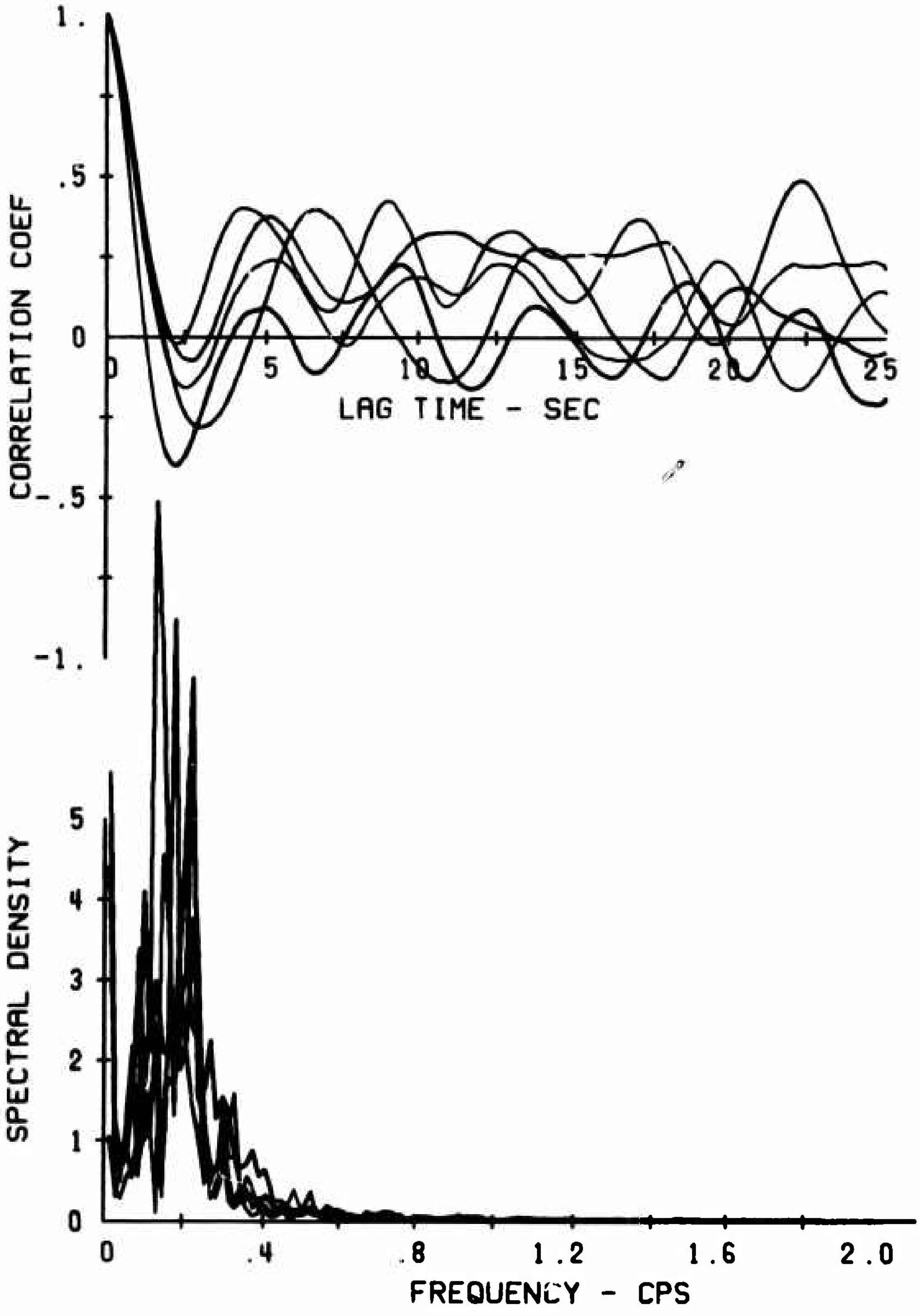


FIGURE 121. LONGITUDINAL STICK PSD, FIGURE "8" TURN, PILOT 3, WING AND TAIL OFF

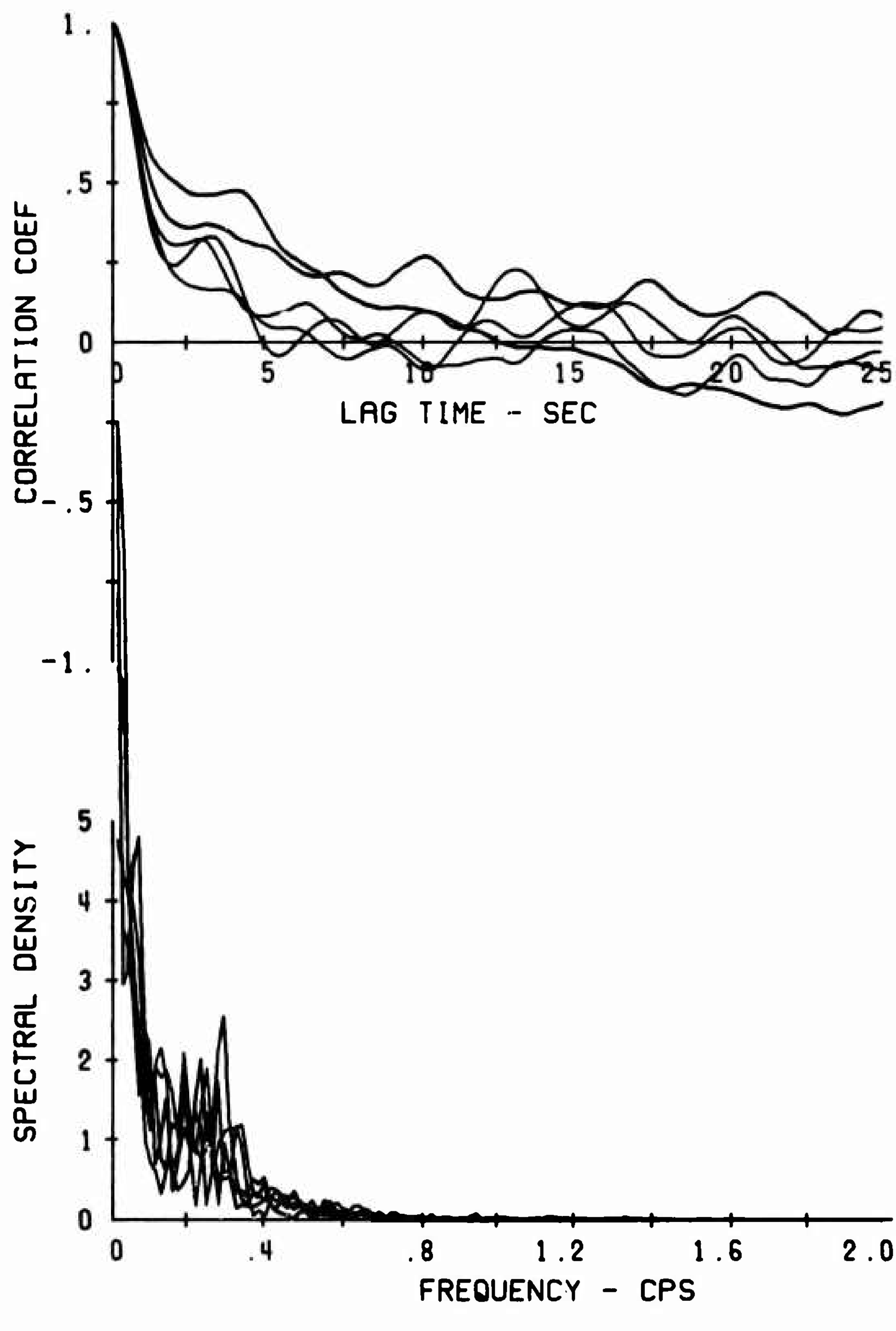


FIGURE 122. LATERAL STICK PSD, FIGURE "8" TURN, PILOT 1, WING AND TAIL ON

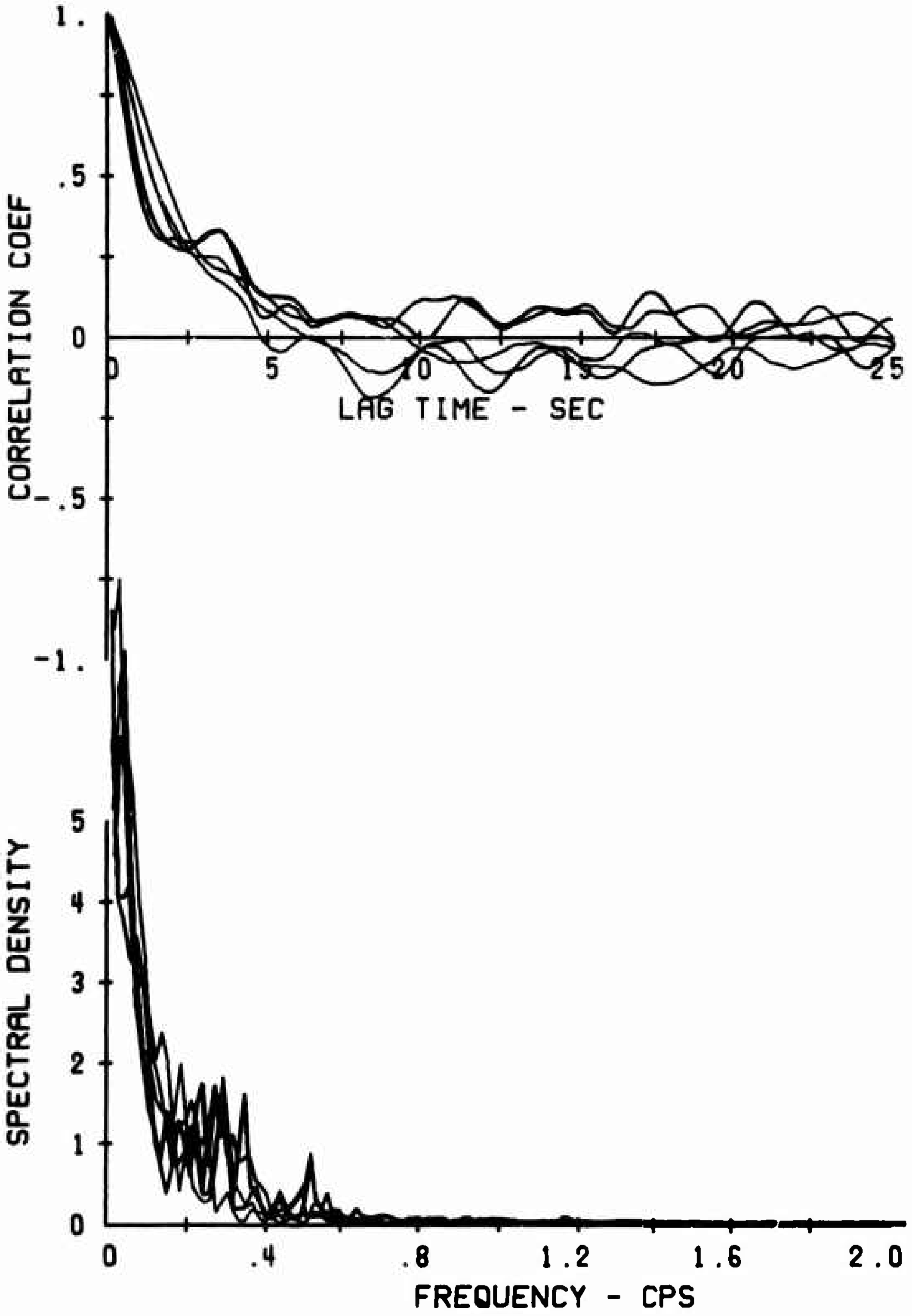


FIGURE 123. LATERAL STICK PSD, FIGURE "8" TURN, PILOT 1, WING AND TAIL OFF

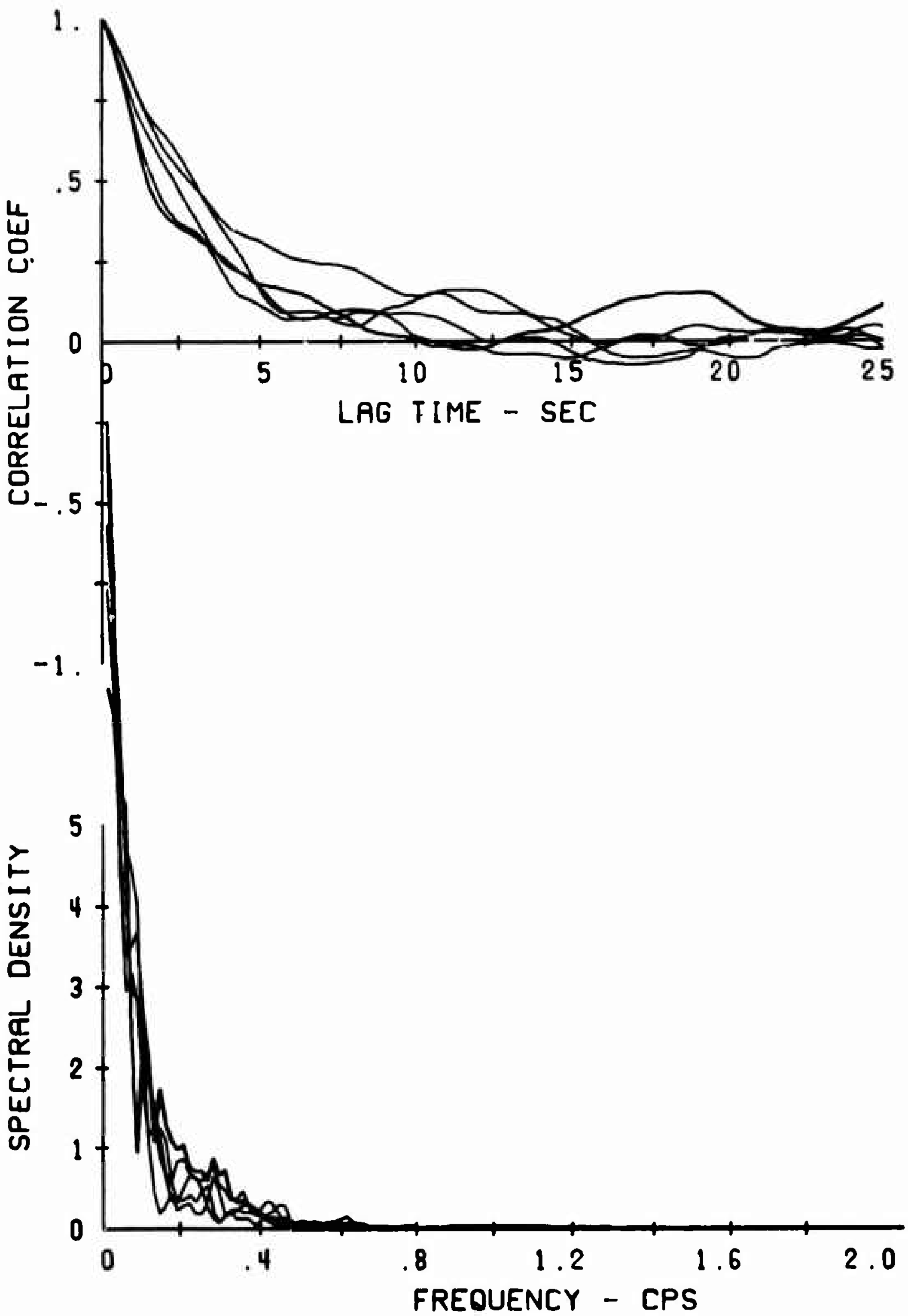


FIGURE 124. LATERAL STICK PSD, FIGURE "8" TURN, PILOT 2, WING AND TAIL ON

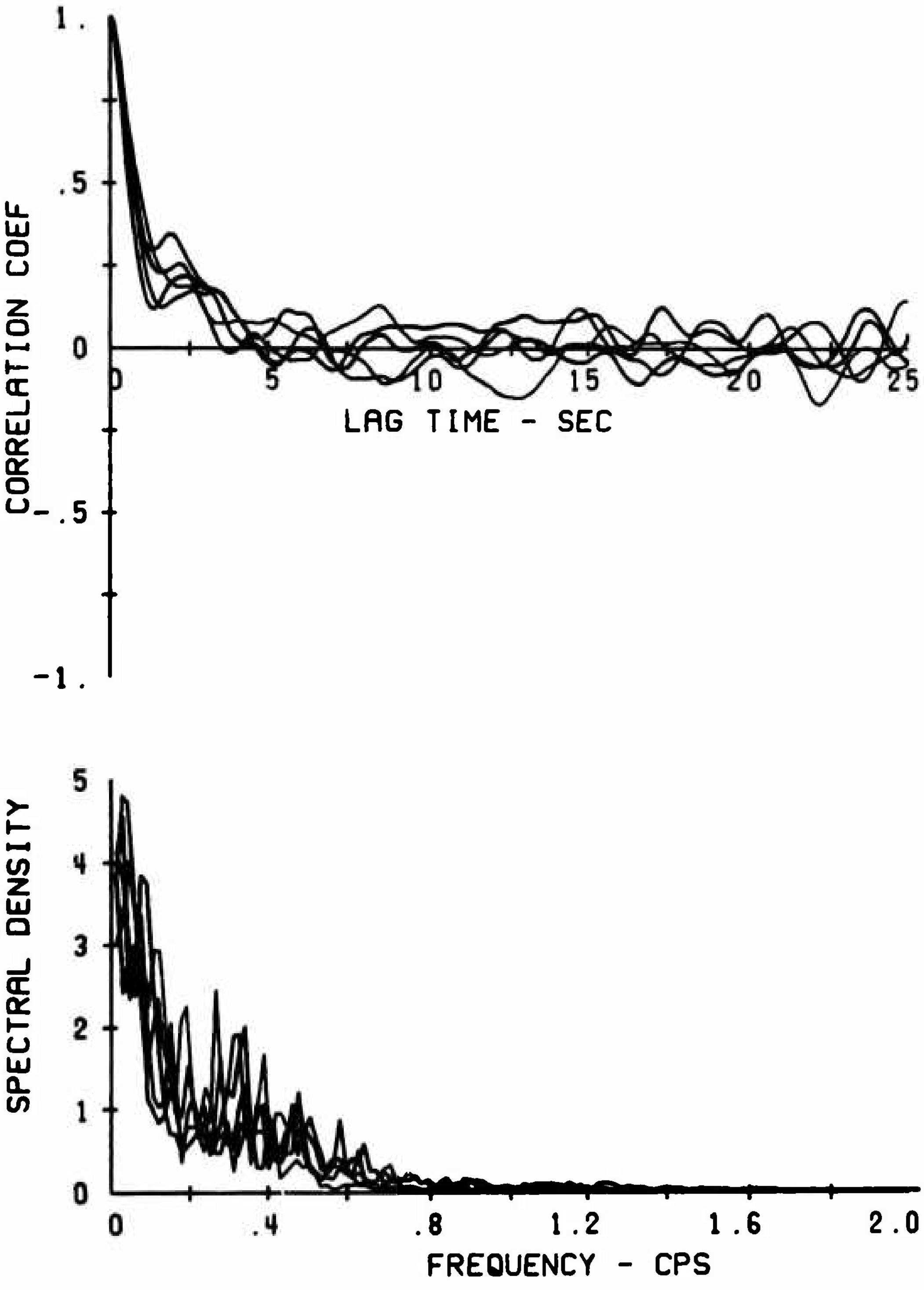
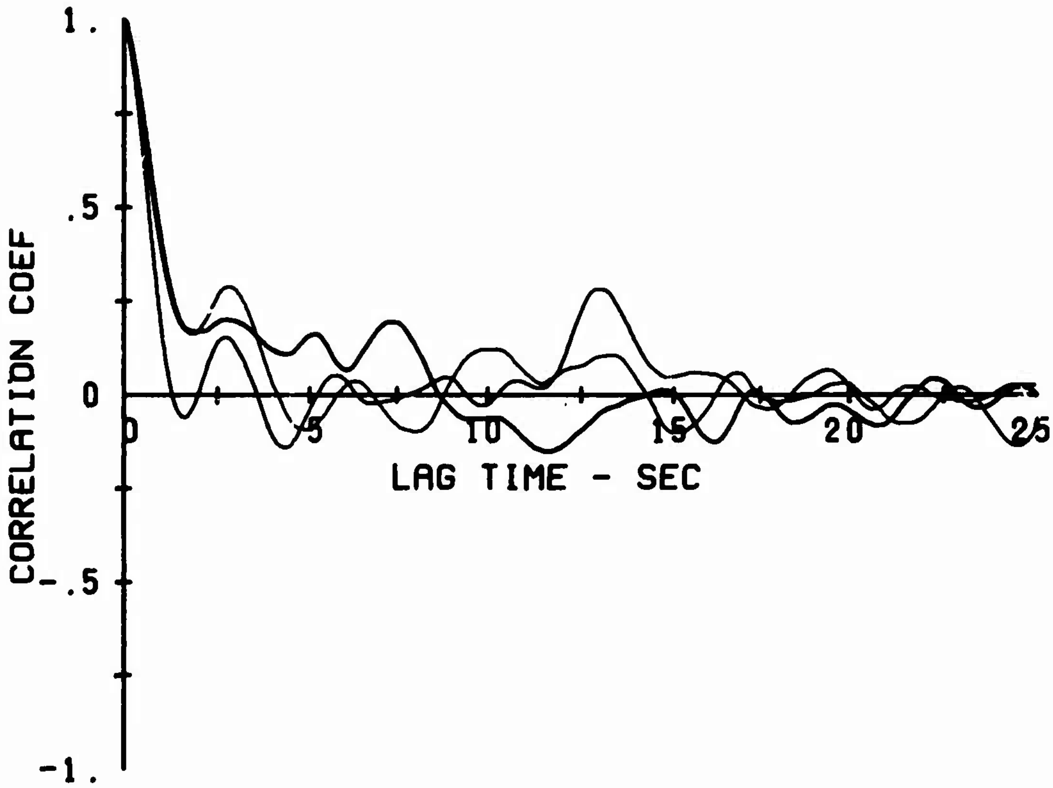


FIGURE 125. LATERAL STICK PSD, FIGURE "8" TURN, PILOT 2, WING AND TAIL OFF



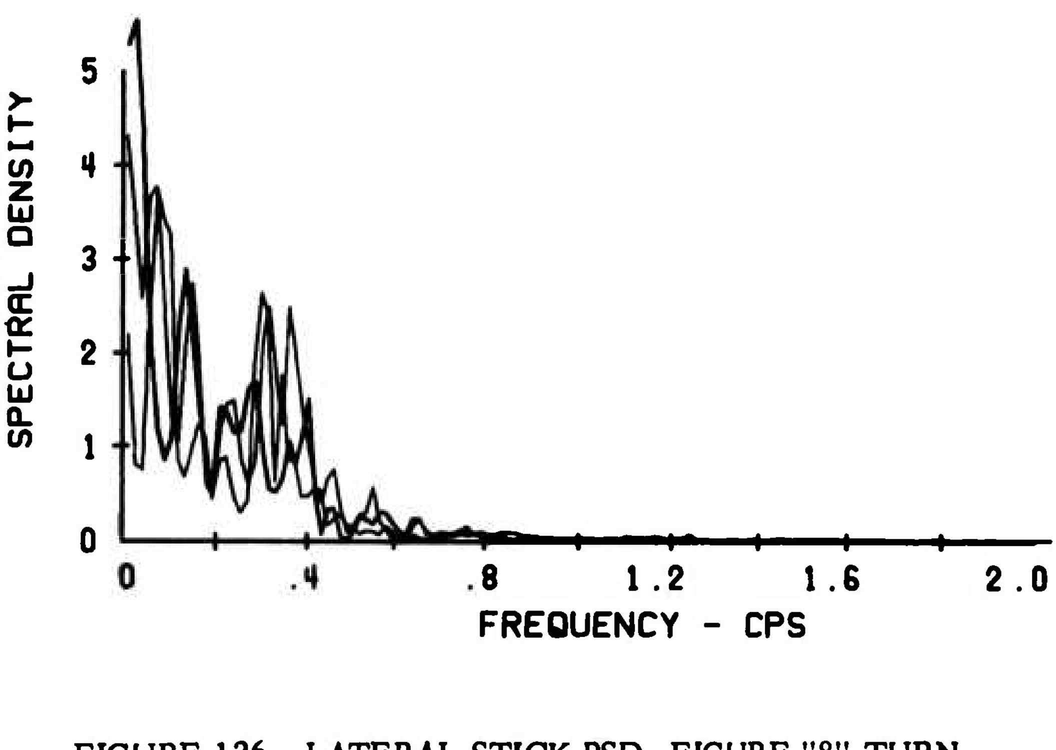


FIGURE 126. LATERAL STICK PSD, FIGURE "8" TURN, PILOT 3, WING AND TAIL ON

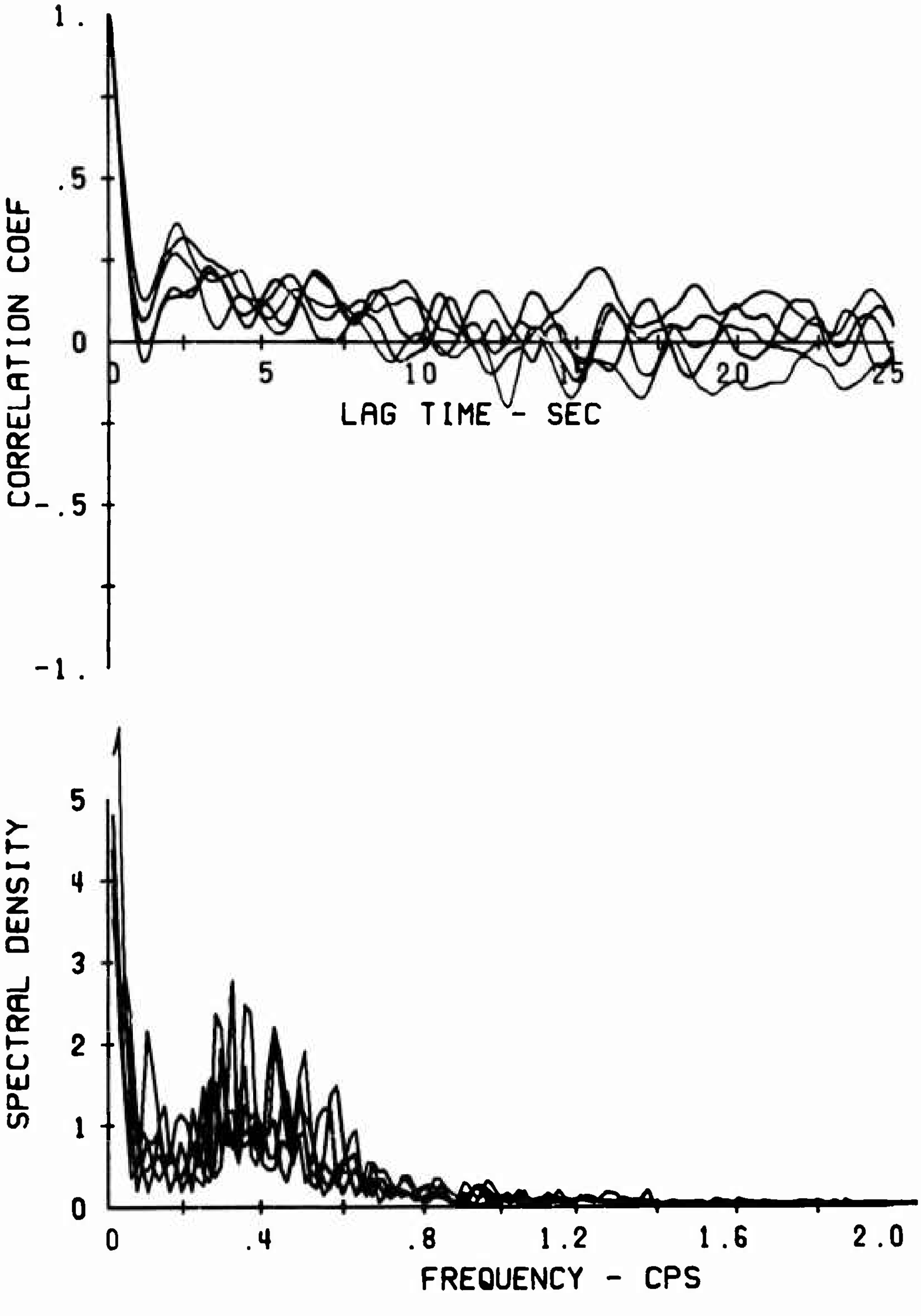


FIGURE 127. LATERAL STICK PSD, FIGURE "8" TURN, PILOT 3, WING AND TAIL OFF

APPENDIX III

FLIGHT TEST PLAN, LOW SPEED MANEUVERABILITY STUDY OF THE S-61F COMPOUND HELICOPTER

Introduction:

Previous studies of compound helicopters have been made to extend their high speed envelopes, with little or no work being done on their low speed handling qualities. This study will provide data to complete the applicable low speed parts of the Mission Task Performance Capability Evaluation form developed by Sikorsky Aircraft under contract DA-44-177-AMC-382(T).

The flight test tasks will be done in three groups to provide for the most efficient use of flight time. The groups will consist of: hover and hovering turns, air taxi over a prescribed course, level flight accelerations and decelerations and figure eight turns. Three pilots will fly each task five times to obtain statistically significant data. All of the "yard work" tasks will be flown in low (preferably 0-5 knots) winds to minimize the effects of variable and gusting winds.

It is intended that the aircraft will be flown with wings and horizontal tail on, and with wings and horizontal tail removed, to determine the effects of these surfaces on aircraft characteristics. One flight will be conducted with the wings and horizontal tail off to qualitatively evaluate handling characteristics at speeds above 60 knots. If undesirable characteristics exist, the level flight accelerations and decelerations and figure eight turns will be flown with the wings removed, but with the horizontal tail installed. (Reference: Proposal Report No. 6344).

The pilots will be asked to rate their performance during each task, using a series of mission task performance rating scales. This rating will be correlated with quantitative pilot and aircraft performance on each task. Performance will be measured, in part, by two 35 mm cameras positioned 90 degrees to each other and to an L-shaped course over which the aircraft will execute the "in year" maneuvers.

Condition Measure

Magnetic Tape: Longitudinal, lateral, collective and rudder control positions; No. 1 and 2 J-60 throttle positions; Pitch, roll and yaw attitudes; Pitch, roll and yaw rates; Normal load factor at the c.g.; Normal, longitudinal and lateral vibration at the pilot's station; Beeper tone event marker.

Photopanel: Altitude, airspeed, rate of climb, outside air temperature, main rotor RPM and event light.

External: Two 35 mm cameras to record aircraft motion in three dimensions and four event lights on the aircraft.

1. Wings and horizontal tail on.

2. Wings and horizontal tail removed.

3. Wings removed and horizontal tail on (as determined by Plan C).

Plan A (Conditions 1 & 2)

Item

1. 360 degree hovering turn (IGE) to the right, maintaining constant altitude and keeping the main rotor mast over a point on the ground.

2. One minute hover (IGE) maintaining constant heading, altitude and main rotor mast position over a point.

3. Same as Item 1, except turn to the left.

4. Same as Item 2, except hover OGE.

5. Air taxi (IGE) forward over an L-shaped course, stopping at the corners, keeping the aircraft's centerline along the course and maintaining constant altitude.

6. Air taxi (IGE) right, left, forward and aft over an L-shaped course, stopping at the corners, maintaining constant heading and altitude.

Item — Plan B (Conditions 1 & 2 (or 3))

1. From a trim hover, with J-60s at idle, accelerate to 120 kn at maximum rate of acceleration, using both J-60 and main rotor thrust. Maintain constant altitude and heading.

2. Trim level flight 120 kn decelerate from 120 kn to a hover at maximum rate of deceleration, maintaining constant altitude and heading.

3. Trim level flight 100 kn (collective pitch fixed in the 80 kn trim position) execute a figure eight turn, attaining a 30° bank angle, in the minimum length of time. Maintain constant altitude and airspeed.

Plan C (Condition 2)

Item

1. Hover at 100% N_R.

2. Take-off and climbout with J-60s at idle.

3. Trim level flight from 40 to 140 kn in 20 kn increments with J-60s idle.

4. Left and right turns at 100 kn with J-60s at idle.

5. Trim level flight 80 kt, 0-60s at idle, increase J-60 thrust to attain 110 kn Execute right and left turns at 110 kn.

6. Increase J-60 thrust to attain 130 kn trim level flight.

7. Approach and landing, J-60s at idle.

APPENDIX IV

THE MISSION TASK PERFORMANCE, PILOT OPINION AND OBJECTIVE MEASUREMENTS QUESTIONNAIRE

Mission Task Performance, Pilot Opinion and Objective Measurements Questionnaires are submitted for the three project pilots. Pilot qualifications and their opinions of the tasks performed are listed. No objective data were put into these questionnaires, because it is dealt with in the text of this report.

PILOT 1

A. Pilot Information

1. Pilot Type: Military ______

   Civilian Test ___X___

   Military Test ______

2. Total flying time in helicopter 3000 hrs, fixed-wing 2000 hrs

3. Total flying time in this aircraft 60 hrs

4. Average time for each task: 1. ____ 2. ____ 3. ____

   4. ____ 5. ____ 6. ____ 7. ____ 8. ____ 9. ____

   10. ____ 11. ____ 12. ____ 13. ____ 14. ____

   15. ____ 16. ____ 17. ____ 18. ____

5. Other pertinent information:

B. Mission Task Performance

1. Hover over a spot in/out of ground effect

Pilot Opinion Rating: , G.W. 17,000 lbs., C.G. W.L. 148.8
STA. 273

Pilot's Comments: Good up to a wind velocity that caused the main rotor downwash to hit the stabilizer.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude speed, etc.

Comments: Good

2. Hovering turn over a spot

Pilot Opinion Rating: , G.W. 17,000 lbs., C.G. W.L. 148.8
STA. 273

Pilot's Comments: Good

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments: Without ASE it is a good work load. (Possible undesirable work load).

3. Deceleration from high speed flight to hover

Pilot Opinion Rating: , G.W. 18,900 lbs., C.G. W.L. 148.8
STA. 273

Pilot's Comments: Takes too long and requires too much nose-up attitude. (The aircraft needs reverse thrust.)

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

4. Air taxi over prescribed course

Pilot Opinion Rating: , G.W. 17,000 lbs., C.G. W.L. 148.8
STA. 273

Pilot's Comments: Good - ASE would help.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

5. Acceleration from hover to high speed flight

Pilot Opinion Rating: , G.W. 18,900 lbs., C.G. W.L. 148.8
STA. 273

Pilot's Comments: Good - Thrust line must be at the C.G. of the A/C or just below.

Task performance objective measurement such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments: Good

6. Roll from maximum load factor coordinated turn to the left into a maximum load factor coordinated turn to the right.

(a) Speed Range from 0 to 80 knots Actual Speed:

Pilot Opinion Rating: , G.W. 18,900 lbs., C.G. W.L. 148.8
STA. 273

Pilot's Comments: Good - Integrated controls will help.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

7. Roll from maximum load factor coordinated turn to the right into a maximum load factor coordinated turn to the left.

(a) Speed Range from 0 to 80 knots Actual Speed:

Pilot Opinion Rating: , G.W. 18,900 lbs., C.G. W.L. 148.8
STA. 273

Pilot's Comments: Good - Integrated controls will help.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

PILOT 2

A. Pilot Information

1. Pilot Type: Military ______________

   Civilian Test ___X___

   Military Test __________

2. Total flying time in helicopter 3000 hrs, fixed-wing 2000 hrs.

3. Total flying time in this aircraft 120 hrs.

4. Average time for each task: 1. _____ 2. _____ 3. _____

   4. _____ 5. _____ 6. _____ 7. _____ 7. _____ 8. _____

   9. _____ 10. _____ 11. _____ 12. _____ 13. _____

   14. _____ 15. _____ 16. _____ 17. _____ 18. _____

5. Other pertinent information:

B. Mission Task Performance

1. Hover over a spot in/out of ground effect

IGE OGE
Pilot Opinion Rating: A6/A4, G.W. 17,000 lbs., C.G. W.L. 148.8 STA. 273

Pilot's Comments: IGE is more difficult than OGE from extraneous yaw inputs and recirculation and rotor downwash on stabilizer. OGE position error increased but pilot work load reduced as a result of recirculation absence.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments: IGE long term position error small, work load high
OGE long term position error large, work load light

2. Hovering turn over a spot

Rt. Lt.
Pilot Opinion Rating: A6/A5, G.W. 17,000 lbs., C.G. W.L. 148.8 STA. 273

Pilot's Comments: Turn about rotor axis abnormal, pilot oriented turn more normal

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments: All errors increase with rotor axis turns. Right hovering turn is a more demanding task than a left hovering turn.

3. Deceleration from high speed flight to hover

Pilot Opinion Rating: A6, G.W. 18,900 lbs.
C.G. W.L. 148.8 STA. 273

Pilot's Comments: Change in pitch sensitivity produces errors as rotor slows to 40 kn. and below. Rotor is not enough to dissipate energy.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments: Altitude error more at higher speeds; flare attitude excessive.

4. Air taxi over prescribed course

Pilot Opinion Rating: Fwd. U7/Rear A5/Left A6/Right A5
G.W. 17,000 lbs., C.G. W.L. 148.8
STA. 273

Pilot's Comments: Direction of movement determines work load and position errors.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

5. Acceleration from hover to high speed flight

Pilot Opinion Rating: Below 20 kn. U8/Above 20 kn. A3
G.W. 18,900 lbs., C.G. W.L. 148.8
STA. 273

Pilot's Comments: Under zero wind conditions, initial 20 kn. requires excessive forward longitudinal stick to overcome stabilizer effects.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments: All axis errors increase during initial acceleration. Rate of acceleration controls position and tracking errors.

6. Roll from maximum load factor coordinated turn to the left into a maximum load factor coordinated turn to the right.

(a) Speed Range from 0 to 80 knots Actual Speed:

Pilot Opinion Rating: U7, G.W. 18,900 lbs.,
C.G. W.L. 148.8 STA. 273

Pilot's Comments: No feel of aerodynamic or control forces; roll rate and slip angle difficult to hold throughout roll to opposite side; all stick positions are not mirror images, thereby making steady-state position of controls difficult.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments: Blade stall encountered on all rolls to right. Blade stall not a consideration in rolls to left.

7. Roll from maximum load factor coordinated turn to the right into a maximum load factor coordinated turn to the left.

(a) Speed Range from 0 to 80 knots Actual Speed:

Pilot Opinion Rating: A7, G.W. 18,900 lbs.,
C.G. W.L. 148.8 STA. 273

Pilot's Comments: Same comments as 6.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

PILOT 3

A. Pilot Information

1. Pilot Type: Military ______________

   Civilian Test ___X___

   Military Test __________

2. Total flying time in helicopter 3000 hrs, fixed-wing 1000 hrs.

3. Total flying time in this aircraft 15 hrs.

4. Average time for each task: 1. _____ 2. _____ 3. _____

   4. _____ 5. _____ 6. _____ 7. _____ 8. _____ 9. _____

   10. _____ 11. _____ 12. _____ 13. _____ 14. _____

   15. _____ 16. _____ 17. _____ 18. _____

5. Other pertinent information:

B. Mission Task Performance

1. Hover over a spot in/out of ground effect

Pilot Opinion Rating: , G.W. 17,000 lbs., C.G. W.L. 148.8 STA. 273

Pilot's Comments: The IGE hover is relatively easy except for occasional rotor wash/horizontal stabilizer interference, which requires excessive longitudinal control displacements. The OGE hover over a flat field is somewhat difficult because of a lack of reference.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

2. Hovering turn over a spot

Pilot Opinion Rating: , G.W. 17,000 lbs., C.G. W.L. 148.8 STA. 273

Pilot's Comments: Pivoting around the rotor head is difficult. Cues are absent. The maneuver is not typical. Normal pivot is cockpit.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

3. Deceleration from high speed flight to hover

Pilot Opinion Rating: , G.W. 18,900 lbs.,
C.G. W.L. 148.8 STA. 273

Pilot's Comments: Maneuver complicated by aux. thrust. First, all speed produced by aux. thrust must be dissipated, as in an airplane, and then purely helicopter techniques are used.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments: Altitude error is predominant, caused by longitudinal overcontrolling and horizontal stabilizer influence.

4. Air taxi over prescribed course

Pilot Opinion Rating: , G.W. 17,000 lbs.,
C.G. W.L. 148.8 STA. 273

Pilot's Comments: No comment

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

5. Acceleration from hover to high speed flight

Pilot Opinion Rating: , G.W. 18,900 lbs., C.G. W.L. 148.8 STA. 273

Pilot's Comments: (See #3) Maneuver complicated by problems of when and how rapidly to add aux. power and also of what collective setting to use. The intermediate speed range is more difficult during transition to "airplane-like" flight.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments:

6. Roll from maximum load factor coordinated turn to the left into a maximum load factor coordinated turn to the right.

(a) Speed Range from 0 to 80 knots Actual Speed:

Pilot Opinion Rating: , G.W. 18,900 lbs., C.G. W.L. 148.8 STA. 273

Pilot's Comments: Easy and pleasant task with good control and response throughout the maneuver.

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

Comments: Airspeed error is predominant because the cyclic is used to control altitude. Thus airspeed depends on the addition and subtraction of aux. power.

7. Roll from maximum load factor coordinated turn to the right into a maximum load factor coordinated turn to the left.

(a) Speed Range from 0 to 80 knots Actual Speed:

Pilot Opinion Rating: , G.W. 18,900 lbs., C.G. W.L. 148.8 STA. 273

Pilot's Comments: Same as comment #6

Task performance objective measurements such as longitudinal and lateral position error, error in maintaining altitude, speed, etc.

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13. ABSTRACT A flight test study was conducted to evaluate the effects of compound configuration on helicopter flying and handling qualities in low-speed flight and to develop task performance evaluation techniques. The S-61F compound helicopter test-bed aircraft was used to perform a series of hover and low-speed tasks while objective measures and pilot opinion data were recorded. The task sequences were first performed in the full compound configuration and then repeated with the wings and horizontal stabilizer removed. This provided data for an evaluation of the influence of the wing and horizontal stabilizer on helicopter flying and handling qualities.

One of the most important findings of this study was the requirement for pilot work load, pilot opinion and actual task performance precision information for a realistic evaluation of task performance capability. None of these measures alone covers the information provided by the two other parameters. Pilot opinion measures were found to lack sufficient uniformity for use as an absolute flying qualities evaluation parameter. In some cases the three pilots expressed different opinions regarding the effect on flying qualities of the same change in aircraft configuration. Measures of control rate and amplitude were found to be a sensitive indicator of configuration changes. The data analyses showed the importance of selecting the proper measures when task performance precision requirements are stated. The results of this study form the basis for further development of mission task performance oriented design criteria.

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Task Performance Measurement						
Sikorsky S-61F						

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